Proceedings of the American Academy of Arts and Sciences.

Vol. XXXIV. No. 8. — January, 1899.

SHORELINE TOPOGRAPHY.

By F. P. Gulliver.

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Presented by W. M. Davis, October 12, 1898.
Received October 29, 1898.

"When I have seen the hungry ocean gain
Advantage on the kingdom of the shore,
And the firm soil win of the watery main,
Increasing store with loss and loss with store;
When I have seen such interchange of state,
Or state itself confounded to decay;
Ruin hath taught me thus to ruminate."

Shakespeare, Sonnet LXIV.

INTRODUCTION.

Physiographic Standpoint. — The present paper deals with the development of coasts from a geographic standpoint, and attempts to work out the criteria by which we may determine whether a given coastal area stands now at a relatively higher or lower level with reference to the level of the sea than it did in some previous cycle or portion of a cycle. Particular emphasis will be laid upon the stages of development, which follow each other according to dynamic laws in a systematic succession, both after uplift and after depression. The time since the beginning of the cycle or epicycle † is found to have a very important bearing upon the question of continental oscillation. The dynamic forces of nature do not leave the initial forms produced by uplift or depression, but produce a successive series of sequential forms, which may be used, when the order of the normal succession is apprehended, as criteria to determine the time since the cycle began.

Omitted Phases of the Subject. — The shoreline, the line formed by the intersection of the plane of the sea with the land, is in a geographic sense a most inconstant line. Though for the geographic minute, a

* This paper was written for the Doctorate of Philosophy at Harvard University, and was presented in June, 1896. It has been condensed and slightly revised for publication. September, 1898.

† See p. 154.

generation of men, it is practically in the same position, yet even in the short period of historic time records show that villages have been submerged, or that seaport towns have been turned into inland places. The historical side of this problem is not to be here discussed, nor is the cause of the secular movements of the earth's crust, including the question of isostasy, here considered.

As dwellers upon the land, we look at the change in the relative position of land and water as it affects our position. Thus "the land rises," "the coast sinks," are the common expressions of man. If the point of view was that of the inhabitants of the sea, the expressions would be reversed, the sea sinks when the land rises and rises when the land is depressed. It will be convenient in this paper to use the terms elevation, uplift, emergence, raised, etc., and their opposites, depression, submergence, sunken, etc., in reference to the land. Such use is not intended to imply a limitation of movement to the land, excluding that of the sea floor, but is to describe the geographic effects from the standpoint of man, who lives upon the dry land.

The shrinking of the mass of oceanic waters will also cause the land apparently to rise to the same amount all over the world.*

By the draining of lakes many characteristic forms of shore development will be exposed, which are here classed with forms following uplift; while the increase of water in a lake for any cause will give the same forms as are produced by a depression of the land.

The relation of the accumulation of glaciers to changes of elevation, and the evidence afforded by coral islands to show rising or sinking regions, are two problems for solution which are not attempted by the present writer.

Use of Terms. — Throughout this paper the author uses *shoreline* for the line of intersection of the sea with the land. The region immediately to the landward of the shoreline is called the *coast,* and seaward from this line the *shore.* Thus cliffs and deltas are coastal features, while waves advance and retreat along the shore.

In the figures the older mainland is cross-hatched, while forelands are left blank. The observer is supposed to look from the point of view of the sea as it attacks the land, therefore the two sides of the figures will be spoken of as the right and left respectively as seen from the sea looking toward the land.

* The effect in inland seas with imperfect outflow has been discussed by Prof. Suess, Anzeiger d. k. Akad. d. Wiss., 1887, XXIV. 180–182.

Initial is here used as the technical term to define the form at the beginning of any geographic cycle or epicycle. Any dynamic process which produces a change in the relative position of land and sea may interrupt a cycle at any stage of development, and introduce a new cycle. Later stages and forms will be called *sequential.* These terms are offered to avoid the misconception, on account of their vernacular meaning, of the terms *constructional* and *destructional,* sometimes used for the identical ideas.

Previous Work on Shorelines. — Since the days of Strabo and Aristotle, two of the greatest observers among early geographers, much has been added to the science of geography. Passing over the work * of the cartographers, explorers, and speculative writers, mention must be made of the great mass of facts collected by Ritter and Humboldt and of their use by Guyot; but the great outdoor observer, De la Beche, whose work was the stock in trade of the next generation, first interpreted many of the coastal forms. He in 1834,† and Dana more fully in 1849,‡ recognized land-carved forms under water, or drowned valleys, as proof of depression of the land. Robert Chambers recognized raised beaches and associated coastal forms, and showed that the Atlantic coastal plain indicated elevation.§ Lyell with his doctrine of uniformity, Ramsay with the theory of marine denudation, the Geikies, LeConte, Darwin, and many other geologists, have worked out the changes in form of coasts here grouped under various sequential stages.

Members of the United States Surveys, Bache, Mitchell, Gilbert, Shaler, Whiting, Davidson, and others, have worked out many of the details of coastal forms and their changes, and a large number of observations recorded upon maps and charts have been the basis of much of the work in this paper.

In 1879, Dr. Hahn discussed the rising and sinking of coasts, but he did not consider the ratios between activities nor take into account the time since which a given movement took place. Weule, Cold, Keller, and Sandler have also studied shorelines, but the fullest discussion of coastal and shore forms has been made by von Richthofen and his pupil, Dr. Philippson.‖

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* See Lyell, Prin. Geol., 11th ed., 1872, 22, 57; Woodworth, Am. Geol., 1894, XIV. 210.

† Theoretical Geology, 192–194.

‡ Geology of the Wilkes Expedition, 1849, 677.

§ Ancient Sea Margins, 221, 253, 270, 276, 299.

‖ See list of references for these and other papers.

PART I. INITIAL FORMS.

1. The Geographic Cycle.

Systematic Sequence of Forms. — Before the consideration of the initial forms themselves is undertaken, the position of the initial stage in relation to geographic cycles of development must be clearly understood. Consequently at the outset some of the general facts of cycles will be discussed in their bearing upon the problem of stages in the development of shorelines, and particularly as regards the initial or first stage of a cycle.

In this paper many facts from different sources are brought together, and the attempt is made to show some of the laws of coastal development. After the inductive study of coast forms upon the better mapped areas of the world had been made, and the deductive scheme of development worked out, gaps in the scheme were found which are not filled by examples. This lack of facts to fit ideal cases may be because they do not exist upon our small earth, or because they have not been reported, as well as on account of a defective scheme. By showing where such gaps in our theoretical scheme of development occur at present, the eyes of future field workers may be sharpened to look for the expectable facts.

Succession on Land. — Land forms go progressively through a series of successive stages of development, to which have been applied names taken from various stages of life, thus suggesting that forms as seen to-day began as something else, and will as time advances become systematically still further developed. Stages of the cycle follow one another from birth to death in the ideal case, where the land stands still long enough for the completed development. The initial stage, or birth, is succeeded in turn by infancy, youth, adolescence, maturity, past-maturity, old age, and finally by death.

A new cycle is inaugurated by each oscillation of any considerable amount, minor changes of level being included as epicycles, or divisions of a cycle. Land forms advance successively from infancy toward old age in each cycle, while any stage of development may be arrested by elevation or depression of the land and a second cycle begun. An essential conception is that a region will be finally reduced to a peneplain if the baselevelling action of the streams, and the other forces of subaerial degradation, be allowed to continue long enough to reduce the land forms to extreme old age. Insequent, consequent, subsequent, and obsequent streams all play their part in the development of the land forms, captures of one stream by another follow unequal chances, while super-

posed streams often come unexpectedly upon a difficult piece of work. Any one unacquainted with the details of this scheme, as worked out by Professor Davis, will be referred to the articles given below.*

Succession on the Coast. — At the beginning of a cycle the subaerial forces of degradation enter upon a new piece of work. Similarly the sea has to begin anew its attack upon an initial coast. A series of coastal forms would be expected to result, and these may be grouped in stages analogous to those of land forms. On account of the many variables which control topographic form, it would not be expected to find the inland area and the coast of the same region in homologous stages of development. The general surface of a coastal plain may be in youth or maturity when its coastline has advanced to adolescence. Because the coastline has reached an adolescent stage of development, it does not follow that the surface of the coastal plain further inland is also in adolescence.

The initial stages of coast and inland surface begin together, for both are controlled by a relative change in position of land mass to sealevel. In making out the initial and sequential stages of shore development from an inductive study of coasts and shores, the writer has tried to follow the principles used by Professor Davis in his studies of the stages of land forms, aided by his critical suggestions during the progress of the work.

The thesis of this paper is: THE FORMS OF ANY COASTAL BELT MAY BE GROUPED IN THE APPROPRIATE STAGES OF A CYCLE. THESE FORMS WILL BE CONSISTENTLY RELATED TO THE ASSOCIATED LAND AREA ON THE ONE HAND AND TO THE SEA BOTTOM ON THE OTHER. WHEN CONSIDERED TOGETHER, THE FORMS OF A COASTAL BELT INDICATE THE RELATIVE TIME SINCE THE LAST CONSIDERABLE UPLIFT OR DEPRESSION, AS WELL AS THE RATIO EXISTING BETWEEN THE SEVERAL ACTIVITIES, IN THEIR DYNAMIC EFFECT UPON THE FORMS OF THE COAST AND THE SHORE.

Rising, raised; sinking, sunken. — In considering any of the consequences of continental oscillations, care must be taken to discriminate between the movement of the land during historical time or the geographic to-day, its movement during the immediate past of geographic time, and the last movement of any considerable amount. Because there is good evidence of either a geologic or a geographic character, that a given land has moved either up or down during the period of more careful observa-

* Nat. Geog. Mag., 1889, I. 12–26, 183–253. Proc. B. Soc. Nat. Hist., 1889, XXIV. 365–423. Am. Nat., 1889, XXII. 566–583. Bull. G. S. A., 1891, II. 541–586. Geographical Illustrations, Harvard University, 1893.

tion of the last century, it does not follow, from such observations *per se*, that the land has moved in that same direction for any length of time previous to the earliest of said observations; and moreover, if in addition to such demonstrated recent movement there exists geologic or geographic evidence to show earlier motion in the same direction, such cumulative evidence of motion in one direction is no valid argument for continued motion in the same direction, for any period of time longer than that required by the nature of the evidence itself. The converse of this proposition is also true, viz. that evidence which shows that a country has been raised or sunken does not prove that the region has been rising or sinking in recent time, or is to-day rising or sinking.

That the time element has been left out of the majority of previous considerations of shorelines, in the discussion of their elevation or depression, will be clearly perceived by any one who will go over the literature of the subject.

Areas of Elevation and Depression as Mapped. — A comparison of three maps of "rising" and "sinking" regions will show how different points of view have led to opposite conclusions. Dr. G. R. Credner considers the presence of large deltas a proof of slow rising, therefore in his map of changes of level * he regards all regions of great deltas as rising. In contrast with Credner's map, compare that of upheavals and depressions by Reclus.† In this map, "drawn after Chas. Darwin," all regions where the coral growth is prevailingly of the atoll and barrier reef type are given as sinking, while those regions where the fringing reefs occur are mapped as regions of upheaval. Thus the hypothesis of Darwin, ‡ who regarded the form of coral construction as evidence of "probable subsidence" and "probable elevation," when given such definiteness as upon the map of Reclus, makes a striking contrast to the map by Dr. Credner; many "rising areas" on the one are "sinking areas" upon the other. Neither of these two criteria can be safely used to show present or recent movement, nor are they more than hypothetical suggestions of earlier changes of level.

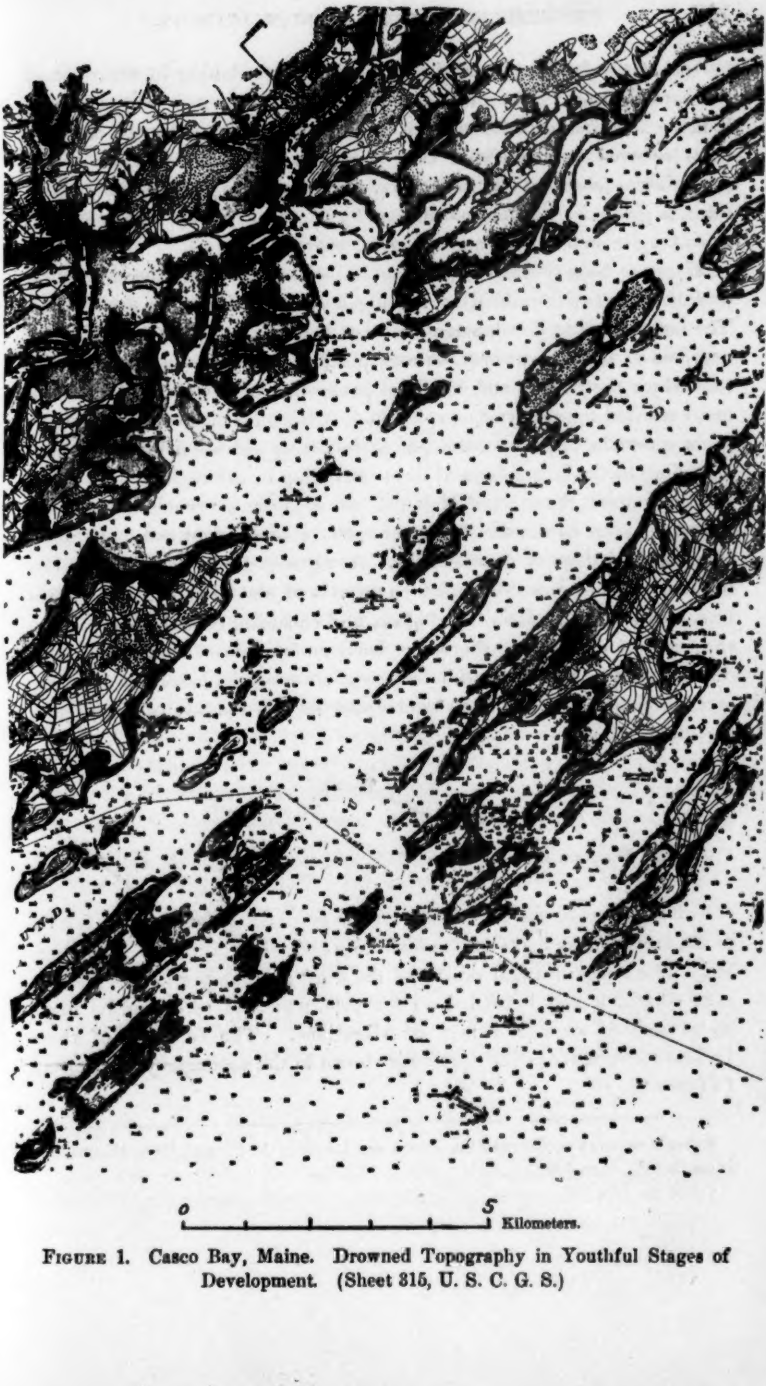
Scandinavia on both of these maps is given as rising, because of its raised beaches and "water-marks." This peninsula, as will be shown later, is in the larger geographic sense in a cycle of development following depression.

An interesting historico-geographic study could be made by a com-

* Pet. Geog. Mitt., Erg. Nr. 56, 1878, Tom. III.

† La Terre, 1872, I. 702, Pl. XXIV.

‡ The Structure and Distribution of Coral Reefs, 3d ed., 1889, Pl. III.



0 5 Kilometers.

FIGURE 1. Casco Bay, Maine. Drowned Topography in Youthful Stages of Development. (Sheet 315, U. S. C. G. S.)

parison of the facts used as criteria of rising and sinking in central and southern Europe. For our present purpose, however, it will suffice to indicate how loosely criteria have been interpreted. Compare the two maps referred to above with that of France by Girard.* Each of the three differs from both of the others. Southwestern France, the Landes coast, is given by Credner as sinking, by Reclus as rising, and by Girard as sinking in some places and rising in others.

Algebraic Sum of Movements: Maine. — The position of the land in the present cycle is determined by the algebraic sum of all past oscillations. The form is due to development in $(n + 1)$ cycles. Cycles and epicycles previous to the present may be recognized in inverse proportion to the time since their close, and in direct proportion to the stage of development reached in said cycle or epicycle. A region is classed in this paper, as in a certain stage of development following elevation or depression, according to the larger facts of form prevailing in the region.

For example, the coast of Maine (Figure 1) is on the whole a depressed region. It has numerous islands, bays, etc., showing drowned topography in a youthful stage of development. At Ogunquit,† however, as well as in other parts of this area, are seen criteria of elevation, elevated shore-line, narrow coastal plain, nip, lagoon, and enclosing offshore bar. Since the greatest depression, there has been an episode of elevation. The development of the sequential features, following the initiation of a new cycle of depression, has been interrupted by this episode or epicycle of elevation.

FIGURE 2. Diagram showing Mutual Relations of Cycle, Epicycle, and Vibration.

Cycle, Epicycle, and Vibration, New Jersey; Scandinavia. — It is only to the larger movements of the land to which the term cycle is applicable. The minor ups and downs of the coast are but portions of a cycle, each of which may be called an epicycle, which in turn may be made up of various smaller swings or vibrations. The relations of these various movements to one another is shown in the accompanying diagram (Figure 2).

* Soulèvements et depressions du sol sur les côtes de France, Bull. Soc. Géog., 1875, X. 225, et la carte.

† See pp. 185, 188.

Professor Salisbury has given us a very pretty example of such epicycles in his Beacon Hill and Pensauken subdivisions of the Yellow Gravel of New Jersey, and of what we may term vibrations in the Jamesburg and later subdivisions.* He has found it possible to determine from the geographic form and position of the deposits the change of level of the coast, though the changes are relatively so small that the evidence of movement cannot be traced far inland. It is possible, on the other hand, to trace the Tertiary peneplain for a considerable distance into the interior, where for instance it is seen in the floor of the Great Valley; while the Cretaceous peneplain is the great surface of reference for geographic features in the eastern United States. These cycle features must not be regarded as the result of some sudden massive uplift, but rather as the summation of minor vibrations and epicycles, during which the average position of the land was such as to cause the Tertiary and Cretaceous peneplains.

Scandinavia (Atlas Univ., 29, 30) is a good example to show the differences between cycle, epicycle, and vibration. Taken as a whole, the peninsula is a depressed region, some portions being deeper drowned than others. Two typical areas will illustrate this. The form of the region around Stockholm (Swe., 67, 68, 75, 76, 77, and adjacent sheets, Swe. Geol., 50, 51, 52, 53) indicates that it was maturely dissected in the previous cycle, and is now submerged to a greater and greater amount out from the shore, as is shown by the large islands near shore, the smaller islands off shore, and the minute islets and skerries out in the Baltic. Baron de Geer makes the axis of greatest uplift in the recent episodes of elevations in the central portion of Scandinavia.† This tilting, at whatever time it occurred, is indicated by the increasing relief in certain directions of the topography of this area.

The second region is in central Norway (Nor., 45, C, D; 46, C, D; 48, B; 49, A, B, C, D; 50, A, B, C, D; 52, B, D; 53, A, C, D; 56, A, B). This area shows adolescent dissection of the upland, the land being more continuous than in the first region mentioned.

While in a large geographic way the Scandinavian peninsula is a depressed area, there have been epicycles of elevation in which terraces have been cut.‡ Recent vibrations are also shown by changes of water level at the established water-marks (R. Seiger).

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* Ann. Rep. State Geol. N. J., 1893, 35–328.

† See references.

‡ See papers by Brögger, Chambers, de Geer, Högbom, Kjerulf, Lyell, Miller, Möhn, Munthe, Pettersen, Reusch, Sandler, Sexe, and Sieger.

Episodes of depression occurring after those of elevation or alternating with them, if they occurred, must have been of short duration, as well as those of elevation, for there is no indication that the development of coastal features has continued for a great length of time at any level since that at which the adolescent to mature dissection took place. A possible exception to the above is the short cycle represented by the rock bench called by Dr. Reusch "the coast plain" (Nor., 6, B; 45, C, D; 46, C; 48, B; 49, A; 53, C; 56, A, B). From the form it is impossible to tell whether this was cut before or after the deepest valley dissection, shown by the present fjords. In his English summary (the writer is not able to read the Norwegian paper) Dr. Reusch says, "It has been worked out in periods previous to the glacial period, and in the intervals of that time." * If it is later than the deeper dissection some traces of the material filling the bays should be found, though the glaciers would have carried off most of the loose detritus.

Volcanic and Climatic Accidents. — In this paper the shore features that result from the accidents, *volcanic* and *climatic*, which are not an essential part of the normal cycle, are not considered in detail. With the general scheme of the normal development of shorelines following elevation and depression in mind, a study of the accidental interruption of the normal succession can profitably be made. The volcanic features as shown in Etna (Italy and Sicily, 269, 270, etc.), and Santorin (Fouqué, Santorin et ses éruptions, Paris, 1879) and the glacial features as seen on Öland island (Swe., 17, 22), in Boston harbor (C. S., 337), Greenland, and Alaska; and the arid coasts of Arabia and the shores of the Red sea, etc., all furnish an attractive field for special study.

Geographic and Paleontologic Criteria. — By the emphasis laid on geographic criteria for the recognition of change of level and time since the initiation of a new cycle, it must not be inferred that the writer implies any lack of confidence in the value of evidence from the position of life forms. Geography and paleontology should go hand in hand in showing past changes of level, as where one fails the other may avail. While historically paleontology has had the lead, perhaps the more natural leader would be geography; then the indications, given by the inductive study of the form of a region, may be confirmed by its contained fossils.

Ideal Areas. — Two areas of strongly contrasted conditions are taken as types. In each area the development of coastal forms has been considered to have advanced to late adolescence or into maturity in the previous

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* See references.

cycle. In the first area the land is supposed to have risen with respect to the water far enough to bring all the features of shore development of the previous cycle above baselevel; while in the second area these features are depressed beneath baselevel. Criteria are worked out for these two normal or average conditions, and later other possibilities will be considered in connection with actual regions.

2. Uniform Uplift.

Initial Stage of an Ideal Area. — Let it be conceived that a region be elevated as a unit to a certain distance above sealevel. The geologic cause of such uplift need not be considered here, as this paper treats of

Figure 3. Ideal Block in Initial Stage following Uniform Uplift. Such a Region shows Smooth Bottom, Simple New Shoreline, Smooth Coastal Plain, Elevated Former Shoreline, and the Dissected Oldland.

the geographic results of continental movements. Enough that it be granted as a possibility of geology that such uplift of a land mass may take place.

The form of the land at the initiation of a new cycle of development is a most important consideration, and it is one which is most frequently left out of the discussions of elevation and depression. The form of the land at the beginning of a cycle depends upon the stage of development reached in the previous cycle, as well as upon the amount and rate of uplift. The ideal case here considered is taken where a coast of homogeneous structure had been developed to late adolescence or early maturity in the previous cycle, and the uplift was supposed to have been sufficient in amount to bring all the coastal and shore forms, developed in the previous cycle, considerably above sealevel; and this uplift took place, not suddenly, but steadily, so that the sea did not have time to appreciably attack the land while it progressively rose. A diagrammatic representation of the resulting form is given in Figure 3. The forms of the shoreline and of the inland and seaward areas will each be separately considered.

(1) *Smooth Bottom.* — The waste from the land, brought down by the streams or worn off the coast by the waves, would have been spread out by the currents in the previous cycle, thus causing the bottom to be smooth out from the new shoreline. In the ideal case which we are here considering, the bottom would consist of the finer waste of the previous cycle, where the sea currents had built it up into the continental delta, at a depth below the deepest wave attack. Such sedimentation in the previous cycle would have filled any irregularities then existing, so that the bottom offshore from the initial shoreline would be monotonously level or gently undulating.

(2) *Simple New Shoreline: Buenos Ayres.* — Where the ocean or other large body of water now intersects the land there will be initial shore features. At first before the waves have had time to attack the coast the outlines will be simple, the land gently sloping toward the sea and ending in broad, undulating curves, probably convex where large rivers enter. As the initial land surface would have but a slight dip seaward, it having been formed under water, the sea would leave exposed at low tide a wide area of flats. The most marked feature in this new born shoreline is its slight crenation and long curves. It would take but a faint convexity of the land surface to give a convex shoreline.

The Argentine Republic southeast of Buenos Ayres has a shoreline upon a gently sloping land, very nearly flat. Before the present chan-

nel was dredged to enable ships to reach the city, the steamers had to discharge their freight into lighters, and these in turn to wagons driven into the water. This region appears to be the one least advanced at present beyond its initial stage, and is therefore given as the best example known to the writer of an initial shoreline following elevation. There is no good account of this coast, the fragramentary hints given by travellers being the only descriptions which we have; and the poor maps (H. C., 616, 930) show little else of coastal and shore forms besides the gently swinging shoreline.

(3) *Smooth Coastal Plain: Texas.* — A coastal plain ought to be found along the margin of the uplifted area, wider where there had previously been an extensive continental shelf, narrower where less waste had been deposited in the previous cycle; but with its inner margin at practically the same height on all sides of the elevated mass. Consequent drainage would characterize this uplifted shelf, while extended rivers from the oldland would flow across the coastal plain as master streams.

The coastal plain of Texas, according to the account given by Professor Penrose,* is a flat plain with the streams lying almost upon the surface, which has a gentle seaward slope. This plane surface appears to be nearly in its initial stage of development. The surveyors report that there is "nothing to map" in this coastal plain area. The shoreline is not consistently related to the surface of this coastal plain, for it has suffered since the elevation a slight episode of depression, as is indicated by the narrow bays, where the sea has entered the lower portion of the valleys, which the coastal plain streams had begun to widen.

(4) *Elevated Former Shoreline: San Clemente*, Figure 4. — At the inner margin of this coastal plain we should find shoreline features younger or older according to the conditions of development of the region before its uplift, but at a practically uniform elevation above the sea at the present time. Reasonable variations in the height of the beach as formed must be expected, but such variations will have to admit of explanation as formed by one water level, as under this head of uniform uplift no differential elevation is understood.

Any of the sequential coastal or shore forms, which will be discussed in Part II., may be found at the level of the former shoreline, and the stages to which these several forms had advanced in the previous cycle should now be found consistently related to each other and to the old-

* First Ann. Rep. Geol. Sur. Texas, 1889, 5–101.

land. The cliff, rock bench and terrace, beach, bar, etc., may all be found elevated above the sea in this initial stage of the new cycle. A good example of a recently elevated shoreline is not known to the writer.

Figure 4, giving a portion of San Clemente island, California (C. S., 607, 671, now 5100, 5127), shows several elevated former shorelines, the last formed being nearly in their initial stage. For detailed description of these cliffs and terraces, resulting from periods of comparative quiet in a series of progressive uplifts, consult the account of the island by Professor Lawson.*

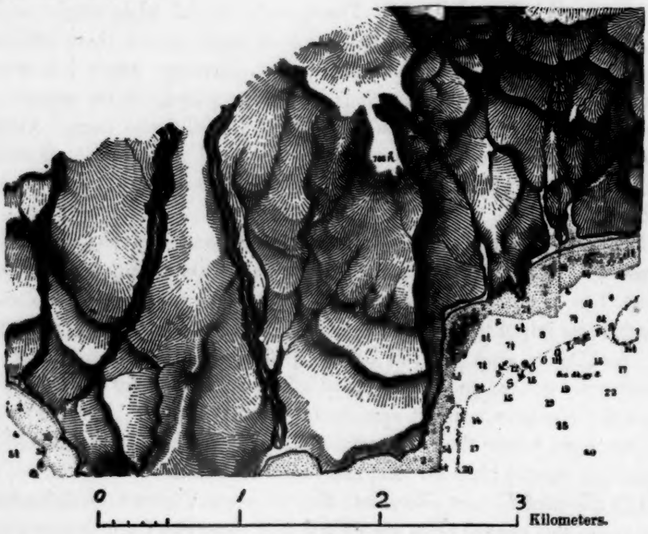

FIGURE 4. Elevated Former Shorelines on San Clemente Island, California.

One of the features characteristic of progressive uplift is clearly shown upon this map, namely, the more advanced stages of stream development farther and farther inland from the shore. The valleys widen as one ascends from the western shoreline, and are shallower on the lower terraces, as is seen on the map. The streams have had more time in which to dissect the higher terraces.

The sequential forms, developed at each level on this island, indicate extreme youth at the time of each uplift; therefore the coastal plain

* Bull. Dept. Geol., Univ. of Cal., 1893, I. 128–133.

and offshore deposits, characteristic of an area uplifted after mature development, which was the condition assumed in the discussion of the ideal area, are not here found. The gently sloping terraces have but scanty covering of waterworn pebbles.*

(5) *Dissected Oldland.* — Upon either hand, as one stood at such a raised beach in the ideal area under consideration just after it had been elevated, strongly contrasting regions would present themselves. Below, the faintly seaward-sloping plain; while above would be seen the dissected oldland. No general criteria for all regions can be given, for the aspect which a given country at this time will present depends entirely upon what stage of development was arrested by its change of position with respect to baselevel. Young, mature, composite, or forms of almost any other possible stage, may be found. The question for the observer to ask is, Where in its path of life did this country stand?

Variations from Ideal Scheme. — Many variations from this ideal scheme will at once suggest themselves. The land may have been depressed but a short time before the uniform uplift occurred, and then the bottom would not have been smoothed over. The coast may have been so steep that all the waste from the cliff cutting was dumped immediately offshore from the rock bench, and only a narrow terrace was formed in continuation of the bench. This is practically the case in San Clemente and in the raised beaches of Scandinavia, already referred to (pages 159, 160), where no broad coastal plain, simple new shoreline, nor smooth bottom is found.

Variations in structure will cause great differences in the coastal and shore forms. A mountain region with its structure transverse to the shoreline, as is the case in Brittany, will show, after an uplift following adolescent dissection, a much more irregular elevated shoreline than in the ideal case of homogeneous structure considered above. A region of longitudinal mountain structure, like the Austrian coast (page 168), would show its characteristic features of development in its elevated shoreline.

Time since the last considerable movement is however the most important factor to be considered in regard to variations from the ideal scheme. If the previous cycle had advanced only to youth, the coastal and shore forms, seen after the uplift in the elevated shoreline, would have the characteristic forms of youthful development. In this case it would be easy to tell whether the second cycle previous to the present was one

* *Loc. cit.*, p. 132.

following elevation or depression, for as will be shown later the forms in the various stages are quite different, as far at least as into maturity. After maturity is reached in the development of forms of the coast and shore, the distinction between a cycle following uplift and one following depression is not so marked.

Slow and rapid Movement.— The initial criteria for the ideal case have been given as if the land were raised at once to a certain height and then stopped, and as if its form were exactly as it had been when developed at a lower level. Such a conception is of course admissible in an ideal scheme, but in the consideration of actual examples the sea will generally be found to have done some work while the movement was in progress. A series of halts may be made in the upward movement, as has been shown in San Clemente (Figure 4). Any speed of uplift may be found in a given locality, and the above criteria must be modified to fit the case under consideration.

Regional and Continental Uplift. — From the uplift of a limited area we may extend the conception to a whole continent, but we must be careful that the criteria are found throughout the whole of the area in which the uplift is inferred. If a whole continent was uplifted bodily, the new shoreline, the coastal plain, and the elevated former shoreline should be found all round its margin, unless some local reason could be given for the absence of one or more of these criteria in a given locality.

Continental movements have been inferred from local phenomena, particularly by writers who have discussed the relations between elevation and glaciation, so that the term as found in the literature is used in a very loose way.

3. Uniform Depression.

Initial Stage of an Ideal Area. — As in the case of uniform uplift an ideal case will be first considered in the study of the initial forms following uniform depression. The ideal case is taken of a region of homogeneous structure, which was developed to early maturity in the previous cycle, and the depression was sufficient to entirely submerge all the forms of the coast and shore developed in the previous cycle. The depression is regarded as having been continuous, though not necessarily rapid. The sea action upon the land during the slow depression was not sufficient in such a short space of time to materially change the mature forms of the previous cycle.

(1) *Uneven Bottom.* — If a region be submerged for a certain amount beneath the sea, the vertical distance being the same on all sides, the

subaerially carved topography would be partly under water. The inequality would be proportionate to the relief of the land still exposed, the change from the more even offshore bottom of the former sea area to the uneven floor of the submerged area being less abrupt the more gradual the depression.

Criteria of submarine form have been very loosely used by writers in the past. In some cases the same facts have been used to prove diametrically opposed theories. Compare the use of inequalities of the bottom by Dr. Spencer and M. Bertrand, the one to prove subaerial denudation in the West Indies at a former greater elevation, while the other considers all such irregularities in the English channel as the result of warping. *

All along the Atlantic shore of the United States, from Maine to North Carolina, submerged channels have been revealed by the detailed soundings of the Coast Survey; and on the Pacific shore Professor Davidson has shown many channels which are not continuations of present river systems. Many of these are however undoubtedly the result of warping, and all have been more or less cloaked over with land waste, so an example surely in an initial stage following uniform depression cannot be given. An example, which comes as near as any known to the writer to being still in a very youthful condition since depression, is in the bay of Maine (C. S., 103, 104, 105, 106), where the soundings indicate very marked submarine channels, which are continuous with land valleys. A small portion of this area is shown in Figure 1.

(2) *Irregular New Shoreline: Scandinavia.* — The intersection of the sea with the uneven land surface produces an irregular shoreline, possessing many drowned valleys or rias † and arms of the sea between headlands and islands. The degree of irregularity depends upon the strength and variety of relief of the submerged area and on the amount of submergence.

For any given area, it is probable that there is a certain medium measure of submergence which will give a maximum irregularity of shoreline. The slopes above and below the water level will be essentially identical, inasmuch as the shoreline lies at a level independent of the form of the land.

The excessive irregularity of a drowned shoreline is well illustrated by the coast of Scandinavia. The coast of Maine (Figure 1) is less irregular, both on account of a less mature dissection before drowning and also

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* See references. † See p. 220.

because this coast is further removed from its initial stage. Puget sound (C. S., 6450, 6460) shows an irregular shoreline with many branching bays, but much more work has been done in this locality since the drowning to simplify the shoreline. Mr. Willis has shown * that this region is complicated by faulting.

(3) *Dissected Land comparable with Submerged Topography: Austrian Coast.* — In from the coast the land would have for its initial form one which is appropriate to the stage of the former cycle, which was interrupted by the relative depression of the land with respect to the sea. The whole region has been supposed to move together, so the streams fit their valleys; therefore if it were not for the many streams now pointing into the same bay, "betrunked" and entering the sea independently, it could not be told from their individual action in the present cycle that their work had been diminished by the submergence.

The type example of drowned longitudinal topography, now in an exceedingly early stage of development since the initial submergence, is the Adriatic coast of Austria (Austr., Zone 24, col. IX, X, XI; 25, IX, X, XI, XII; 26, IX, X, XI, XII; 27, X, XI, XII; 28, XI, XII, XIII; 29, XI, XII, XIII; 30, XII, XIII, XIV; 31, XIII, XIV).

The cliffs on the more exposed land are older than where better sheltered. It is a region of Mesozoic and Eocene strata of the Jura or Appalachian type of folding, maturely dissected when drowned, into whose longitudinal valleys the sea has entered, forming characteristic drowned valleys of the longitudinal type. † In many places the slopes intersect the sea level without a trace of having been attacked by the sea since the depression. Following these slopes under water we sometimes find them continuous with the unsubmerged portion, while in other places the soundings indicate a rapid change from steep to gentle grades. A detailed geological map with sections showing the structure of the Jurassic, Cretaceous, and other strata is needed to show whether these rapid changes of slope under water are due to structure, to baselevelling, or to aggradation during a slow depression. The central portions of the sounds and channels bordered by the inner shoreline have broad flat areas ranging in depth from 70 to 95 meters.

The general accordance of level of these bottoms suggests as the most

* Chi. Jour. Geol., 1897, V. 99.

† See various articles in Austrian journals by the following geologists: Bittner, A.; Hauer, Franz Ritter v.; Hilber, V.; Petermann, A.; Stache, Guido; Tietze, Emil; and Toula, Franz.

probable explanation of their origin that they represent the areas reduced close to baselevel during the previous cycle, when the land mass stood higher and was dissected to maturity. Such lowlands would be slightly cloaked over during a gradual submergence. Such slow depression is indicated by the bays almost filled by deltas with no bay-bars at their mouths. A period of gradual sinking, slow enough to allow delta growth to fill the valleys as they went under water, and fast enough to prevent much cutting of cliffs and building of bars, would account for the existing combination of initial shoreline with bays nearly delta filled.

Infantile islands, minutely irregular shoreline, projecting headland, and unfilled bays are characteristic of the southern portion of this area. The depression has no doubt varied slightly in time and amount in different portions of this region, but as a whole it is a remarkably good example of drowned topography close to its birth.

Other Examples. — A few other examples of drowned topography that have advanced but slightly from their initial stages are here given, with but a word of comment in the several cases. Special features in these areas which show an advance from the initial condition are considered later under the several headings in Part II. All these regions taken together with Austria, the type of longitudinal drowned topography, give an idea of the various types of forms resulting from the drowning of subaerially carved topography. In several cases the depression may not have been absolutely uniform.

The beautiful Christiania river system developed to adolescence before drowning (Nor., 9, A, B, C, D; 10, A, B, C, D; 14, B, D; 15, A, C; 19, B, D; 20, A).

The meandering valley form of Kolding fjord argues strongly for submergence of subaerially carved topography (Denm., Fredericia, Bogense, Skamlings Banke).

The meandering valley above Haderslebener lake is continued in Haderslebener fjord with swings of proportional radius of curvature (Germ., 7, 12, 13).

The drowned valley of the Warnow river below Rostock is about the same size as that above the city (Germ., 86).

Greece and the coasts of the Ægean sea (Atlas Univ., 40; Attica; maps in Der Peloponnes). Dr. Philippson has shown in his monograph on the Peloponnesus that this region is dissected into many blocks by diastrophism.* This causes rocks of differing resistance to be near one another; thus on this account, and also because of the stronger sea action in certain places, one finds adolescent development replacing the more common youthful forms upon the coasts to the north.

Clarence strait, Revillagigedo channel, and Portland canal, Alaska, show the typical ramifications of subaerially carved topography (C. S., 8100, 706).

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* Der Peloponnes, 418–432.

Variations. — As in the case of uniform uplift (p. 165) there will be great variations from this ideal scheme of criteria for uniform depression. The stage of development interrupted by the drowning, the steepness and structure of the coast, and the rate of submergence, all have important bearing upon the form of the depressed coastal and shore forms. Slow sinking while the sea cuts into the land will materially aid the formation of a planation surface. Professor von Richthofen goes so far as to consider all regional plains of abrasion, "Abrasionflächen," as necessarily the work of the sea aided by slow submergence.*

The gradual depression and cloaking over of a region are the normal results of the isostatic return to a condition of equilibrium. Stripping in one area and loading in another causes a lack of balance, which will be restored by a rising of the stripped, and a sinking of the loaded area. One of the best examples of isostasy is seen in the Mississippi basin.†

Now while the principle of isostasy explains some regions of slow depression with concomitant sedimentation, it does not account for the more pronounced changes of level, introduced by secular elevation or depression. Geographic cycles are not introduced by isostatic movements. The suggestions of cause are numerous, but these geological questions are not considered in this paper. The subject is here dismissed with the statement, made by Major Dutton, that "the nature of the process is, at present, a complete mystery." ‡

4. Diverse Movements.

Tilting; Position of Pivotal Axis. — Uniform uplift and depression have been considered, and the resulting initial forms contrasted in the two cases. If, instead of a uniform uplift throughout the area, the movement is diverse, we have tilting, warping, or crumpling and faulting. If the change of quantity proceeds at a constant rate, we have rigid tilting; if at a variable rate, but of moderate variety, we have warping; while if much irregularity of rate appears, we have disorderly crumpling or faulting.

With the exception that the topographic forms are elevated or depressed to different amounts in various places, the criteria of tilting are the same as those already discussed. Tilting may be of such a character

* Führer für Forschungsreisende, 1886, 354.

† See the following articles: McGee, A. J. of S., 1892, XLIV. 177-192; Bull. G. S. A., 1894, VI. 55-70; Keyes, Bull. G. S. A., 1894, V. 231-242.

‡ Phil. Soc. Wash., 1889, XI. 63, 64.

as to give criteria of uplift in one portion of the tilted region and those of depression in another.

The former shoreline in a tilted region, unless the axis of tilting was parallel to the general direction of the coast, would not be level, as it was found to be in a region uniformly uplifted. It will be progressively higher away from the axis on the side of elevation, and will be more irregular in height the more sinuous the shoreline before the tilting took place. The raised beaches around lake Ontario, taking Dr. Spencer's elevations of the Iroquois beach, show a very nearly even tilt.

The position of the pivotal axis, as pointed out by Professor Shaler,* gives differing results, and thus the criteria differ for the several cases. The pivotal axis may lie parallel to the coast, at right angles to it, or in any intermediate position. This axis may be at the shoreline, inland from the coast, or seaward from the shore. The tilting itself may be of two kinds; either the seaward slope may be increased, or diminished. These various possibilities will cause many variations in the quantity and quality of the criteria.

Topography of Tilted Regions: California; New England. — A two-cycle history of a region, in which an uplift occurs between the first and the second, causes the development of composite topography. When, however, the uplift is not uniform, a new element comes in; the topographic forms developed after a tilt are not only composite, but are also inclined with respect to baselevel. Those forms of land, which were developed with reference to one spheroidal plane when it coincided with baselevel, are tilted, so that this spheroidal plane of the first cycle forms throughout the region a constant angle with the plane of the sea in the second cycle. The first cycle of course may be in any stage of development when the tilt is made, but the recognition of the tilt will be progressively easier the later the stage reached before tilting.

A peneplain extends north for a hundred miles from about the fortieth parallel to the great bend of Pit river, California.† This plain is tilted at an inclination of 100 feet to the mile toward the east, and is canyoned by streams 300 to 400 feet deep, which have not yet reached grade. "The cañons in general are deepest to the westward and gradually run out to the Sacramento river in the newer deposits which fill the valley. It is evident that since the baselevel was formed, it has been affected by

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* Mem. B. Soc. Nat. Hist., 1874, II. 337.

† J. S. Diller, Jour. of Geol., 1894, II. 32-54; 14th Ann. U. S. G. S., 1892-93. Pt. II. 429; W. Lindgren, Bull. G. S. A., 1893, IV. 257-298.

differential elevation in the uplifting of the Coast range and Klamath mountains, just north of the fortieth parallel, to the extent of over 2,000 feet." *

A slope of small angular value, viz. 0° 8′ 5″, across the State of Massachusetts carries the southern New England peneplain to an elevation of twenty-five hundred feet in a distance of one hundred and sixty miles. As one stands upon the peneplain in the western part of Massachusetts, he may look to the southeast across an almost even surface of denudation with here and there a monadnock rising above it, a monument of resistant rock.

Warping: New Brunswick, N. J. — The definition of a warped surface here adopted is that given in geometry, namely, a surface generated by a straight line moving so that no two of its consecutive positions shall be in the same plane. Various cases under warping may occur, the marked characteristic of them all being the variability of the criteria.

In the depression or uplifting of the Schooley peneplain † there appears to have been a warp, which causes the portion of the Cretaceous peneplain near New Brunswick to be lower than the rest.

Santa Catalina Depression. — Professor Andrew C. Lawson has described ‡ a very beautiful instance of differential movement between San Pedro hill on the mainland and San Clemente island. Upon the southern California coast and also upon San Clemente are many well marked sea-cliffs rising one above another to an elevation of some 1500 feet.§ These show pauses in a progressive series of uplifts. But between San Clemente island and San Pedro hill lies Santa Catalina island (C. S., 5100), whose land sculpture shows subsidence and not elevation. Upon this island (C. S., 5128, old number 613) there is a good example of a divide almost submerged. Professor Lawson says that the sea-cliffs show more rapid recession than is usually found in stationary or rising coasts. He considers this Santa Catalina depression an orogenic, or local movement, which occurred at the same time or later than the epeirogenic or general uplift, shown by many observations along the coast of California.

Crumpling and Faulting. — Cycles and epicycles caused by uplift or depression merge through tilting, crumpling, and faulting into those inaugurated by mountain-building. A graded series of forms may be con-

* Jour. of Geol., 1894, II. 45.

† Messrs. Davis and Wood, Proc. B. Soc. Nat. Hist., 1889, XXIV. 380.

‡ Bull. Dept. Geol., Univ. of Cal., No. 4, 1893, I. 122-139.

§ See p. 164 and Figure 4.

ceived, and largely filled in with examples, beginning with the area uniformly uplifted and ending with a highly complicated mountainous region. This interesting subject falls outside the province of this paper.

PART II. SEQUENTIAL FORMS.

5. Sea Attack and Transportation.

Differential Abrasion. — Varying hardness of rock is an important factor in subaerial degradation, and it must also have considerable to do with the attack of the sea upon coasts. The two ways of formation of plains discordant with the rock structure have been contrasted thus: "A subaerial baselevel plain is gradually completed by the action of ordinary forces on all parts of its surface," while "a submarine platform is essentially completed strip by strip, once for all, as far as it goes." * Professor Shaler has recently called the monadnocks, the residual masses of harder rock rising above the New England upland, "the most enduring evidences of marine action." †

Without entering into the discussion whether the New England monadnocks were formed by subaerial or submarine denudation, it is the purpose of the writer to use these contrasting interpretations of the same phenomenon as an introduction to the discussion of the effect of relatively hard and soft rock upon marine denudation. Waves will attack softer rock more rapidly than its more resistant neighbor. A promontory of hard rock may thus be formed where the less resistant rock on either side has been eroded by the sea. The ocean, however, tends to convert irregular to straight or gently swinging coasts.

If the land therefore remains at the same level there will come a time when the increased cutting upon the exposed promontory will equal the lessened wearing of the softer material in the re-entrants on either side. After such equilibrium is reached the shoreline will march inward, practically strip by strip. If, on the other hand, there is a gradual sinking of the land, decided inequalities of surface due to differential marine erosion may be covered by the offshore deposits. This has been pointed out both by Professor Shaler and by Professor Davis in the papers quoted above.

Monadnocks versus Marine Remnants. — A distinction should be sought

* Messrs. Davis and Wood, Proc. B. Soc. Nat. Hist., 1889, XXIV. 375.

† Bull. G. S. A., 1895, VI. 149.

between the remnants above a submarine platform and the monadnocks rising above a subaerially carved peneplain. The burying by slow submergence would tend to protect from decay the sea cliffs and benches, so that when re-elevated and divested of their sedimentary protection, the marks of sea action would show marine origin, at least in part. A depressed peneplain with its monadnocks would also show cliffs and benches, if it remained in its descent at one level for a time sufficient for cutting. Features of shore development must not then be considered as distinguishing between monadnocks and marine remnants.

The vital question is how far the cover extended inland, and what point the former shoreline reached. Inside this limit all differential erosion remnants will have been formed entirely by subaerial degradation, while on the seaward side of the line the sea will have had more or less to do with their formation. After the form of the old shoreline has disappeared, and the coastal plain sediments been more or less completely stripped off, the evidence for the former greater inland extension of the cover will lie in the arrangement of the streams. The area formerly covered will show superposed streams and less perfect adjustment of rivers to structure than is found beyond the limits of the former shoreline.*

Coastal Inequalities. — Many writers have ascribed all inequalities of the coast to differential erosion of the sea. Even as late as 1882, Prof. A. H. Green implies that all bays and other coastal inequalities are due to "the hardness and structure of the rocks." † The tendency in America of later years has been to ascribe all inequalities of the shoreline to the drowning of subaerially carved forms. While submerged topography will account for the greater part of such irregularities, we must not entirely leave out of the consideration the action of the sea.

The agents of the sea are the waves,‡ tides, and currents. Writers differ widely in what they attribute to each of these three agents, and a discriminating study of the work of the three should be made by some careful observer. The present writer is inclined to attribute the attack of the sea largely to the waves, and its transporting action largely to the tides and currents.

* See Messrs. Davis and Wood, Proc. B. Soc. Nat. Hist., 1889, XXIV. 399-410; Professor Davis, Lond. Geog. Jour., 1895, V. 128-138.

† Physical Geology, 577.

‡ For the method of wave attack see Gilbert, Mon. I., U. S. G. S., Chap. II., with references; Lyell, Principles of Geology, 11th ed., 1872, I., Chaps. XX.-XXII.; LeConte, Elements of Geology, 2d ed., 1882, 31-43; Penck, Morphologie der Erdoberfläche, II. 460-497, with references.

Wave-cut Islands. — On the Marblehead coast of Massachusetts we see the more rapid erosion of the trap dikes which intersect the more resistant granite.

Sir Charles Lyell has given instances of differential marine erosion in the drongs of the Shetland islands.* The granite and other harder rocks longer resist the waves than the schists. The many veins of porphyry in Hillswick Ness, Lyell shows, will also in time similarly be etched.

The Orkneys and Shetlands are exposed to violent sea action, and since the shore evolution is here considerably below grade, this is the place where differential abrasion might be expected. The best maps of these islands † show many outlying islets, high stacks, and low skerries, many of which are probably due to abrasion of the sea since the drowning of this region.

Wave-cut islands are typically seen along the west coast of Ireland. Probable occurrences are in the following areas (Ireland, 9, 51, 83, 93, 103, 160, 171, 204).

In the Southern rapids of Peril straits, Alaska (C. S., 8259), the sea is now actively eroding. The current, according to the Coast Survey, is often running ten knots an hour, and the tides between Pinta head and Eureka ledge run with terrific velocity. All the conditions are here favorable for the production of wave-cut islands, and an examination of the charts shows many islands, rocks, and ledges entirely isolated from each other. The sea has here made no attempt to simplify the irregular shoreline by connecting bars.

"Approached by sea, the Aleutian islands seem gloomy and inhospitable. . . . An angry surf vibrates to and fro amid outstanding pinnacles." ‡

Off cape Tschipnuski, Kamchatka, numerous rocky islets, stacks, and skerries are seen upon the map, and in the sketch of Lieutenant Rogers (H. O., 54).

At Blanca and Concon points (H. O., 1232), and at Guacache, Cobija, and Guasilla points (H. O., 1181) on the coast of Chile.

Algodonales point, west of Tocopilla, Chile (H. O., 1265).

Submarine Platform. — The late old-age of shore development, where the land has stood approximately at the same elevation for a period of time sufficiently long for the sea to have carried out its intention, is the submarine platform, the plain of marine denudation. This plain will not lie as far below the surface of the sea as it did in its maturity. The broader expanse of the submarine platform beneath the ocean will prevent the sea from so actively attacking the coast. From birth to maturity the sea pushes its zone of maximum action farther and farther inland, while from maturity to old-age the atmospheric agencies will supply more waste than the shore currents can take care of, and the offshore depth will gradually decrease, though the shoreline will move landward at a lessening rate. The steep cliffs of maturity will diminish in height as old-age comes

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* See figures, Principles of Geology, 11th ed., 510, 511.

† Roy. Scot. Geog. Soc., Atlas of Scotland, Edinburgh, 1895, sections XLII, XLIII, XLIV, XLV.

‡ W. H. Dall, Sci., 1896, III. 44.

on, and at a late stage will show as little elevation as was seen in the youthful nip.

While the sea has produced the submarine platform, the land has been worn down by subaerial degradation to a peneplain.* The controlling plain for the production of the peneplain surface is baselevel, "the level of the sea . . . below which the dry lands cannot be eroded." † The surface will never reach baselevel, but will approach it, "in an infinite series of approximations like the approach of an hyperbola to tangency with its asymptote." ‡ A possible qualification of the above statement may be, that where the surface is near baselevel, the wind may excavate a portion down to or even below sealevel.

American and English Views. § — Major Powell, Major Dutton, Mr. Gilbert, and other geologists who worked upon our western interior region, saw the great importance of sea-level as the controlling baselevel down toward which the land is worn. The action of the sea did not enter into their considerations to any extent. The English geologists on the other hand saw upon their island the great destruction wrought by the waves, and the lower level of wave action was their most important plane of reference. Professor Ramsay included the subaerial forces as aids in marine denudation, while later Dr. Geikie ‖ made sea cutting of less importance than subaerial denudation in the production of the plain of marine denudation.

FIGURE 5. SL = sea level. WB = wave-base. P = peneplain. SP = submarine platform. CD = continental delta.

Wave-Base. — The two planes of control should be distinguished, and the almost plains produced by subaerial and submarine degradation be given separate names. Figure 5 shows the relation of the peneplain surface with its controlling baselevel to the submarine platform and its

* W. M. Davis, A. J. of S., 1889, XXXVII. 430.

† J. W. Powell, Exploration Colorado River of the West, 1875, 203.

‡ C. E. Dutton, Tertiary History of the Grand Cañon District, Mon. II., U. S. G. S., 1882, 76.

§ Since the following section was written, Professor Davis has made a more extensive comparison of the American and English schools; Bull. G. S. A., 1896, VII. 377–398.

‖ Scenery of Scotland, 1887, 137.

controlling wave-base. The term wave-base is here introduced as a comparable term to river baselevel or hard stratum baselevel. It is another local baselevel, which ought to be distinguished from the grand baselevel of the sea.

Thus, at a late stage of development, the peneplain and the submarine platform almost merge into each other; indeed, so much do the forms resemble each other, that the one process or the other has been given by many writers as explaining the total degradation toward a plain. The plain of marine denudation, perhaps better called the submarine platform, is distinguished from the peneplain by its cover of offshore deposits, and the limits of this cover, even after it is partly stripped off, can be found from the arrangement of the drainage.

The need for a separate term for the controlling plane from that of the surface, down to which the forces of degradation are able to reduce the land, is shown when one examines recent writings upon this subject. To speak of the deformation of the baselevel * is like saying a bent cone in conic sections. Both terms imply abstract mathematical surfaces that cannot suffer distortion. The peneplain may be uplifted, tilted, warped, or folded, but not the baselevel. In the same way it is helpful to distinguish between the submarine platform and the wave-base. The offshore erosion surface will approach the depth to which the maximum wave action is possible, but the submarine platform will be cut to that depth only in the zone of maximum wave activity.

Sea Transportation. — When the supply of waste has increased beyond the power of the various currents to immediately deposit it offshore, transportation alongshore will become more important, and aggradation may take place in certain places. The tendency of shore currents is undoubtedly to form curves in the shoreline which will be satisfactory to the particular current acting.

The writer makes the following distinction between the sea action upon the inner shoreline, which includes the more protected coasts of bays, drowned valleys, sounds, channels, etc., and its action upon the outer † shoreline, which is that of the exposed coasts of the ocean. The ocean currents have little direct effect upon the inner shoreline, and the wind has not opportunity to develop, by the formation of waves, current eddies of large radius of curvature upon inland waters. In these narrow arms of the sea the tidal currents are the preponderating force, for here

* Diller, 14th Ann. Rep. U. S. G. S., 1892–93, Part II., 406; Jour. of Geol., 1894, II. 45.

† See Penck, *loc. cit.*, II. 551.

the ocean current and the local wind current do not have a chance to be relatively so effective. It may be stated as a general principle that the most effective agent of shore development upon the inner shoreline of drowned topography is the tidal current. Broad bays form a middle ground where any of the three forces may be the strongest. Upon the outer shoreline the ocean eddy currents are the most effective, while upon lakes and inland tideless seas the local wind currents are the most important factor. The movement of the land waste is in all three cases due largely to the action of the waves.

Offset; Overlap; Stream Deflection. Figures 6, 7, 8. — The three criteria of form by which the dominant current alongshore may be inferred are offset, overlap, and stream deflection. The three usually occur together, but each is found alone.

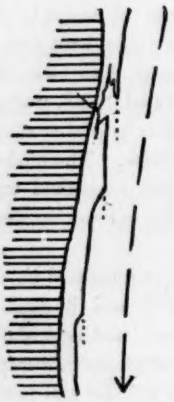

FIGURE 6. Offsets.

FIGURE 7. Overlaps.

FIGURE 8. Stream deflection.

Types of offset without accompanying overlap are given in Figure 6. Overlaps are commonly accompanied by offsets of the shore curves in the same direction, as is markedly the case in Fire Island inlet, Long island (C. S., 119). One shore curve offsets another when the curve itself or the continuation of the same passes to seaward of the next succeeding shore curve. When this offset is slight, it may be perceived by looking along the shore curve, putting the eye close to the map.

The typical example of offset without overlap is on the west coast of Jutland (Denm., Thisted), where the currents are known to be from the

south, which is in this case the right.* The right shore curve systematically offsets the left along all the western coast of Denmark.

Many examples of similar offsets are known along the coasts of the world, and wherever the dominant current is known from observation the offsets follow this law: THE CURRENT FLOWS FROM THE OUTER CURVE TOWARD THE INNER ONE. On account of the number of cases in which the offsets agree with the observed currents, it is pretty safe to conclude when offsets occur systematically in one direction that the dominant movement alongshore is in all probability from the curves which offset toward those which are offset.

Figure 7 shows typical overlaps. The right hand curve of the outer shoreline laps over the next succeeding curve of the outer shoreline. A curve which overlaps the succeeding one generally offsets it as well, though in places, as is shown in the lowest example in Figure 7, the up-current curve may intersect the down-current one if extended far enough. This occurs where the factors of alongshore transportation are probably changing, and the down-current curve is really made up of two curves, and the up-current curve offsets the down-current one in each case.

The overlap is an intermediate form between the offset and the deflected stream. A graded series of examples might be given from simple offset through various combinations of overlap to a case of stream deflection without any offset.

Along coasts which are formed of unconsolidated materials, it is frequently observed that rivers, brooks, or tidal channels aim toward the sea for a certain distance and then turn and run along nearly parallel to the shoreline, and finally empty to the right or the left of the point which would have been their direct course to the sea. The river's intention to reach the sea as quickly as possible is evidently not carried out where such deflection is seen. Some disturbing force has come in. There seems little doubt that this force is the current alongshore, which has turned the outlet of the stream. Such has been the explanation of many authors.† Figure 8 shows the relation of current to deflection of streams.

Dominant Current. — There is probably wave movement in both directions along the shore at different times, and the form shows in which

* H. Möhn, The North Ocean, Norwegian North Atlantic Expedition, 1876–78, 2, XVIII. 168, Plate XLIII.

† De la Beche, Geological Notes, 1830, II. 11, Plate I. Fig. 3; Reclus, La Terre, 1870, I. 447; Sir A. Geikie, Textbook, 3d ed., 399.

direction the dominant movement has taken place. The dominant movement may not always correspond to the prevailing movement alongshore. A few severe storms causing a strong current from the right during one month might determine forms, which a weak current from the left prevailing for eleven months of the year would not be able to efface.

FIGURE 9. Typical Current Cuspate Foreland.

Current Cuspate Forelands: Type, Figure 9.* — In adolescence, when the currents have more load than they can carry, it is deposited in forelands of various forms. A characteristic one is the cuspate, of which a typical drawing is given. In it are combined those features of the three Carolina capes † and cape Canaveral (Figure 10) which the author deems important to show the method of growth. Former positions of the shorelines are indicated by the ridges of dunes built by the wind along the shore.

Such former positions are beautifully indicated in Canaveral (C. S., 160, 161), where three or four successive positions of the outline of the cusp, each farther to the left than the preceding, are delineated, besides many lines of aggradation in each position (Fig. 10). Similar lines of growth are seen at cape Fear, where the present right shoreline cuts off the eastern ends of the four dune ridges extending east-southeast from the lighthouse and curving sympathetically with the left shoreline.

Cape San Blas, on the west coast of Florida (C. S., 183, 184), shows four stages on the right side and nine successive stages of aggradation on the left side.

A more striking example of aggradation lines is seen in the cusp of Dars cape in the Baltic (Germ., 61, 62, 63), where thirty-eight systematic and successive shorelines are indicated by dune ridges (Fig. 11). The dominant current is from the right, according to the offsets and hook at the point of the cusp; but the thirty-eight successive shorelines suggest a gradual aggradation of strips, and a change from an earlier condition when the current was from the left. The tidal flats, east of Zingst, point to present transportation and growth toward the left.

* For fuller account see Bull. G. S. A., 1896, VII. 399–411; also see references for papers by Abbe and Tarr.

† See p. 242.

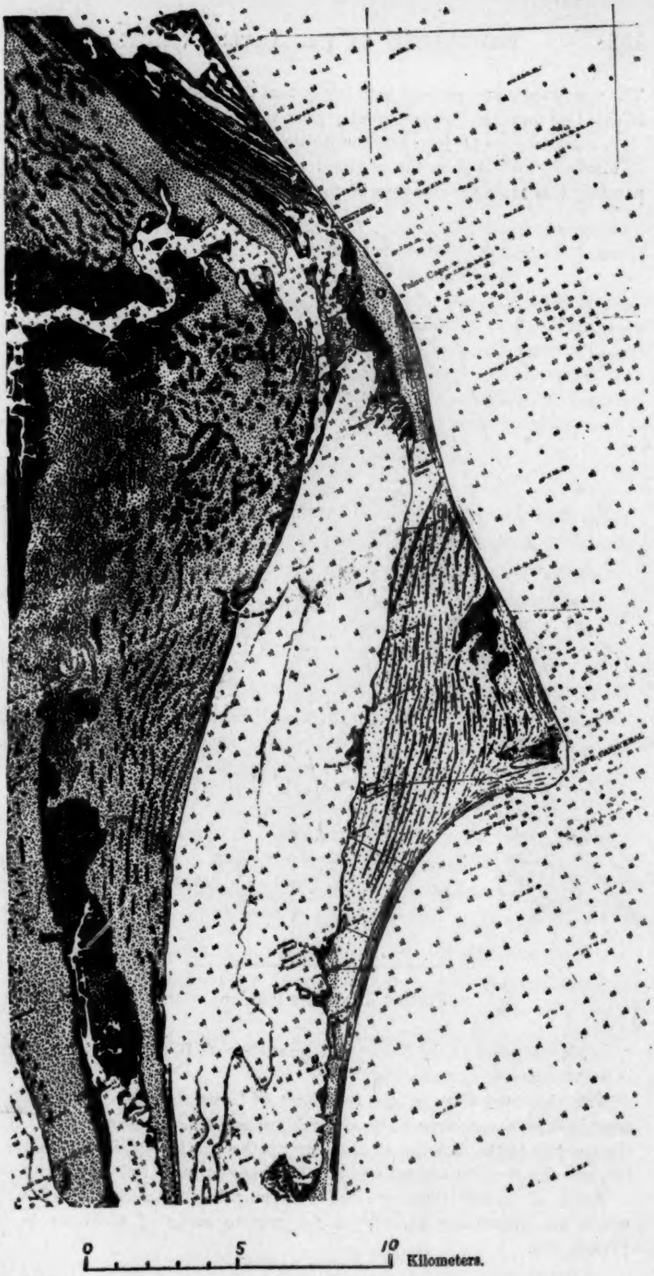

FIGURE 10. Canaveral Foreland, Florida. (Sheet 161, U. S. C. G. S.)

The topography and geology both imply that this offshore bar is built up of several islands tied together. A very pretty problem for field study is here presented.

A rounded cusp projects into the Baltic north of Wismar bay (Germ., 85).

Markelsdorfer Huk on the northern end of Fehmarn island is a foreland of apparently this same general type of formation (Germ., 40).

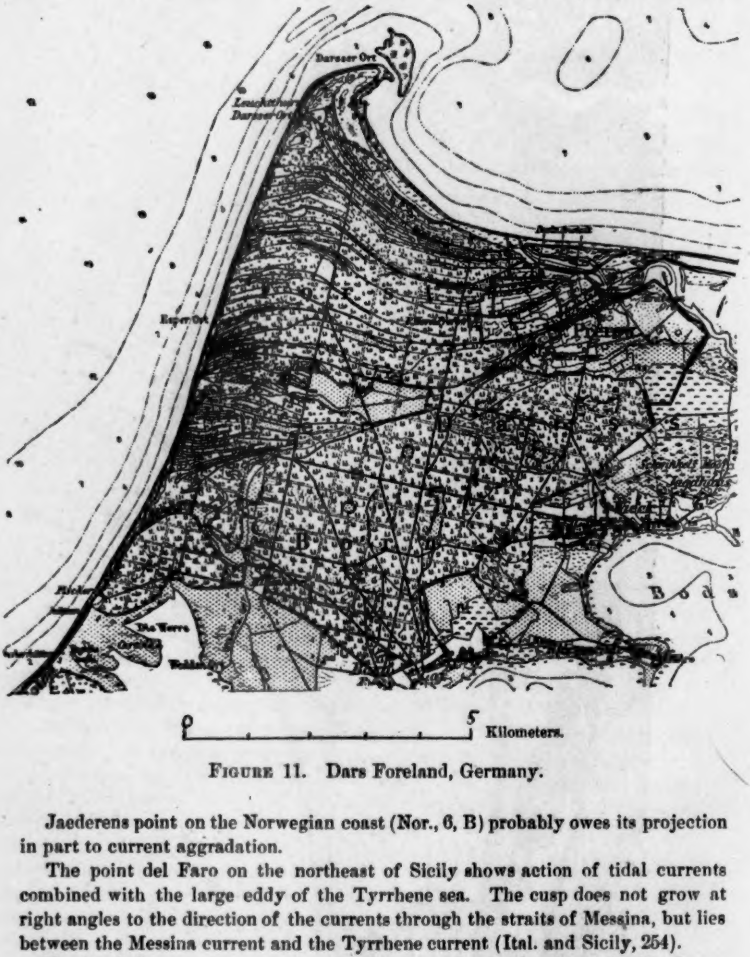

FIGURE 11. Dars Foreland, Germany.

Jaederens point on the Norwegian coast (Nor., 6, B) probably owes its projection in part to current aggradation.

The point del Faro on the northeast of Sicily shows action of tidal currents combined with the large eddy of the Tyrrhene sea. The cusp does not grow at right angles to the direction of the currents through the straits of Messina, but lies between the Messina current and the Tyrrhene current (Ital. and Sicily, 254).

North of Sousse there are two solid cuspate forelands, covered with dunes, which are apparently built by a progressive series of additions to the coast (Tunis, 57).

In small water bodies, lakes and seas nearly without tides, the winds would cause waves which in turn would originate currents of smaller radius of curvature, which should produce smaller cuspate forelands. The cuspate points in the Danish waters are probably such forelands. These are seen on the topographic maps of Denmark in the following localities: Roskilde fjord (Denm., Hilderöd), Söen Mellem Smalandene (Denm., Saxkjöbing, Vordingborg), Limfjorden (Denm., Lögstör), on Langeland and the islands to the west (Denm., Svendborg, Nakskav, Gulstav, Faaborg), and in other localities along the Danish and German coasts.

The Bonneville cuspate forelands are proportional to the currents which existed on the old lake and are similar in size and outline to the Danish cusps. Professor Russell also reports V-bars upon the fossil shores of lake Lahontan.* These cusps seem to have been built upward as the waters of the lakes rose, but the water level never remained constant long enough for the lagoons to have become filled, forming solid forelands, since Mr. Gilbert reports only a partial silting up.†

6. Offshore Bar.

Shelving Shore. — When the sea takes a new position of attack after elevation, if the shore is shelving, wave-base intersects the smooth bottom at some distance from the simple new shoreline, and the point of maximum wave abrasion is out from the coast at some point on the shelving shore. This condition would obtain in the ideal case assumed in Part I. From the forms of observed shores which slope gently beneath the water, the action of the sea appears to be somewhat as follows. The waves at first beat upon the coast and cut a faint cliff or *nip*. The point of maximum wave action is offshore, and there the waves heap up sand from the bottom and a bar is formed alongshore. The waves abrade rapidly until the offshore bottom to seaward of the bar approaches wave-base. During this deepening the waves have broken farther and farther offshore, so that the bar has gradually moved seaward. When now the bottom to seaward of the bar has been abraded almost to wave-base, a condition of shore-grade is reached: the sea is able to transport and build into the continental delta whatever waste is supplied from the bottom and offshore bar. As soon as material is taken from the bar it will retreat toward the land.

Stages. — The period of upbuilding and seaward growth of the offshore bar has been regarded as the youth of the shoreline, and the period of cutting back as adolescence, since the latter is a graded condition. During youth the seaward growth of the bar leaves long marshy strips, or "slashes," between the successive dune ridges formed along the shoreline. These become overgrown with bushes, peat, etc. The lagoon behind the

* Mon. XI., U. S. G. S., 93.

† Lake Bonneville, 121, Pl. XVIII.

bar also is frequently converted into marsh. In the landward retreat of the shoreline, this vegetable layer is discovered at or beneath sealevel, covered by the beach sands, as on the New Jersey coast.

When the offshore bar has been completely cut back, the nip has been extinguished, and the sea is actively cutting into the coastal plain, leaving a more or less pronounced sea cliff, maturity is reached.

No Offshore Bar. — When the initial slope of the coastal plain is so steep that the sea is able to begin the production of the submarine platform immediately offshore, shore-grade is quickly attained, youth and adolescence are of short duration, and the coast reaches a mature stage of development without the production of an offshore bar. This has probably been the case in eastern Italy (page 186).

Youth: Texas. — The offshore bars on the Texas coast are very marked features in that elevated region (C. S., 205, 206, 207, 208, 209, 210, 211, 212). An apparent earlier position of the bar is shown by the string of small islands inside the present offshore bar. The sea is here building apparently from the bottom in great measure. The transportation alongshore as indicated by many offsets, Cavallo pass, Galveston entrance, etc., is dominantly from the left, caused doubtless by the eddy circulation in the gulf of Mexico. There are occasional stream deflections to the left, as Cedar bayou and San Bernard river, which are caused possibly by backset eddies from the main circulation. The littoral forms in this region are complicated by an episode of slight drowning. A great variety of dune forms are shown on this bar.

The map of Costa Rica by Dr. Frantzius* shows a characteristic offshore bar. The scale of the map is too small to show indications in which direction the bar is moving, so this may be an adolescent coast.

The eastern coast of Corsica (Fr., 261, 263, 265) shows an offshore bar, but whether advancing or retreating, the writer does not know.

Off the Ogunquit-Wells Beach coast there is an offshore bar upon which the writer could find no evidence as to which way it is moving.

The offshore bars on the Atlantic slope are further advanced on the whole than the Texan bars. Youthful bars prevail in Texas, and adolescent ones from North Carolina to Long island. Field study of these bars is needed to bring out more fully the history of the sequential forms. The following quotation shows the meagre character of existing descriptions.

The offshore bar opposite Beaufort harbor, N. C., "is mostly covered with a low pine and mixed growth, and its average width is about half a mile; the sand hills and ridges upon it are from 20 to 35 or 40 feet high." †

Adolescence: Southern New Jersey. — The Geological Survey of New Jersey reports that the sand dunes overlie a layer of black soil along the shoreline, at differing heights at different localities. The lagoon along the southern coast of New Jersey is largely converted into marsh, while that along the central portion of

* Pet. Geog. Mitt., 1869, XV. 81, Tom. V.

† H. L. Whiting, U. S. C. G. S., 1851, Appen. 28, 483.

the State is little filled, indicating an earlier stage. In the northern portion of the State the offshore bar merges into the southern wing of the Long Branch behead-land (page 213).

Upon the south side of Long island the sea has devoured the land to an appreciable extent during the historical period. Meadows and cultivated lands have been covered with sand, wagon tracks in peat have been found on the ocean side of the dunes, while peat, cedar stumps, and tangled roots occur to-day between the sand hills and the sea. These traces of land life seaward of the dunes indicate a march of the dunes landward,* and a general pushing of the offshore bar inland.

7. Dissected Coastal Plain.

Surface Form. — On page 155 it was shown that the stage of development of the surface of a coastal plain may not be the same as that of the coastline of the same region. This subject comes more properly under the cycles of development of land forms; but, since the coastal plain is one of the main criteria of uplift, the sequential forms will be briefly sketched.

Mr. W. Lindgren shows a characteristic section of a Quaternary coastal plain lying on a granite oldland,† but he does not use its stage of dissection to show the time since the elevation of the region around San Diego.

Youthful Dissection: Ogunquit, Maine. — In southern Maine the forms indicate that there has been a recent episode of uplift revealing a narrow coastal plain, which fills in the irregularities of the coast made by a previous depression. The streams have only begun to intrench themselves upon this late deposit.

The Monopoli coastal plain on the "heel" of the Italian boot shows youthful dissection of a marine plain (Ital., 190, 191). The Pliocene strata‡ present a surface gently rising from the sealevel to heights of from 100 to 200 meters at the foot of an abrupt slope of Jurassic and Cretaceous rock. This slope rises from 75 to 250 meters above the plain, and has the form of an elevated former sea cliff now slightly dissected. A problem for field study is the cause of the minutely ragged outline of the present shoreline.§ There is no offshore bar shown with this coastal plain, which may be accounted for by the fact that the slope of the surface of the coastal plain is considerable, 100 meters in 5 kilometers, and therefore it is probably steep enough for the direct attack of the sea. The coastal plain character of the heel of Italy is well shown on the topographic sheets by the radial arrangement of roads (Ital., 202, 203, 204, 213, 214, 215, 223). The towns are like the hubs of wheels, the spokes of which are the highways. The distribution of infaces, streams, and outcrops suggests that the area has been developed in several cycles, a study of which in the field would be most attractive.

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* A. G. Pendleton, U. S. C. G. S., 1850, Appen. 8, 80, 81.

† Proc. Cal. Acad. Sci., 1888, L., Pl. III.

‡ Carta Geologica d' Italia, 1 : 1,000,000, Roma, 1889.

§ See page 239.

The Pyrgos coastal plain on the western end of the Peloponnesus shows characteristic intrenching consequent streams.*

The Sykonia coastal plain, south of the gulf of Corinth, is much complicated by faults.† The streams are frequently lost in crossing the gravel of the youngest step.

Adolescent dissection: Eastern Italy. — Eastern Italy, north of the "spur," from Pesaro to Termoli, is a coastal plain of Pliocene strata ‡ dissected by consequent streams now aggrading (Ital., 140, 141, 147, 148, 155). There is indication of captures, particularly in the Pescara, Saline, Vomano, and Sangro rivers, but study upon the ground is needed for proof. Several streams show cutting of the right bank more than the left, Biferno, Fortore, Sangro, Pescara, and Tavo.

Many portions of the Atlantic and Gulf plains of the United States, and of the North German plain show characteristic adolescent dissection.

Mature Dissection: Eastern Virginia. — The form of the surface of the dissected Neocene strata east of Richmond, Virginia, indicates mature dissection. The slight drowning of the streams indicates that since dissection there has been an episode of depression.

A portion of the coastal plain of southern Sicily where there is the least deformation shows quite typical mature dissection (Ital. and Sicily, 272).

Adjustment of Drainage. — A characteristic feature of maturity is the adjustment of streams according to the structure of the region. The most perfect mature adjustment will result from (1) considerable diversity in the size of the initial consequent streams; (2) considerable altitude of the land-mass; (3) considerable diversity of resistance in the strata that are cut through by the streams; and (4) a significant amount of inclination in the strata. § Two successive cycles of uplift will give more complete adjustment than a single cycle.

8. Fading Elevated Shoreline.

Lake Shorelines. — Although some of the finest known examples of initial elevated former shorelines occur upon shores abandoned by lake waters, nevertheless these forms as seen to-day have entered their sequential stages and are fading away. This fact has not been forced upon the reader's attention in the articles upon lake shorelines, and he is left to infer that an elevated former shoreline remains as it was left by the retreating water. Of course the shoreline of a lake, whose water has

* Dr. A. Philippson, Der Peloponnes; topographical and geological charts, sheet I. section IV.; text, 321–323.

† *Loc. cit.*, sheet II. 118, 153; also see Der Isthmos von Korinth, Z. d. G. f. E., 1890, XXV. 1–98.

‡ Carta Geologica d' Italia, 1 : 1,000,000, Roma, 1889.

§ W. M. Davis, Lond. Geog. Jour., 1895, V. 133, 134.

abandoned its former stand on account of the removal of its barrier or down-cutting of its outlet, is in the topographic sense as truly an elevated former shoreline as if the land had been raised. The relative position of land and water is changed.

Typical forms of Bonneville. — Many of the illustrations of shore forms of the Bonneville, Provo, and levels intermediate in position between lake Bonneville and Great Salt lake serve as types of elevated former shorelines, in youthful stages. The deltas, terraces, embankments, cliffs, V–bars, bay-bars, and the tying of islands to the mainland are all characteristically shown. The stratigraphic and paleontologic proof of the relative age of the shorelines is brought out by Mr. Gilbert, but the fading features of the older shorelines are not dwelt upon to show relative ages.

Lake Agassiz. — The descriptions of the shore forms of the ice-dammed glacial lake Agassiz are given in this same manner, as if the forms were formed once for all and would forever remain as constructed. Gen. G. K. Warren set aside the hypothesis of an ice-barrier and argued for an actual change of level, depression to the south accompanied by a rise to the north. Mr. Upham has traced the various beaches formed by the different water levels and shown them to have been the result of an ice mass to the north gradually retreating toward Hudson bay. These elevated former shorelines rise from south to north and from west to east, in the direction of the former ice-fields, the amount of slope varying from zero to one and one third foot per mile. Since these old shores must have been horizontal when formed, their present position shows a tilting since the time of lake Agassiz.

Marine and Lake Terraces. — Early writers used the beach form to show elevation,* but they often did not distinguish between the seashore forms and those which had been produced by water above the sealevel. One of the most fruitful sources of error has been in regarding the terraces of ice-dammed lakes as produced by marine action. The classical example is that of the Lochaber terraces, the Parallel Roads of Glen Roy. For an historical discussion of the change of view from the detrital dammed lake to the action of the sea and finally to the present hypothesis of an ice-dammed lake, see "The Great Ice Age," by Professor Geikie. † The geographic criteria for the differentiation of the similar forms produced by these two processes are these. At the level of the

* R. Chambers, 1847, and many later writers.

† 3d ed., 1895, 282–285.

supposed ice-dammed lake the terraces will be approximately continuous except where the ice stood. On the drift barrier hypothesis it was very difficult to explain how the terraces remained while the barrier was removed, but the ice-barrier would disappear by simple melting, and therefore the terraces would remain in nearly their initial form after the retreat of the ice and removal of the water. The upper terrace level would correspond in elevation with the height of the col over which the lake discharged. This relation to the col has been worked out in considerable detail in the study of the Great Lakes.* A reliable geologic criterion is the occurrence of marine shells, which are found in marine beaches but not in ice-dammed lake terraces.

Examples. Raised beaches are found in Ireland on the north coast, in Killary harbor, along Kenmare and Glengarriff bays, and elsewhere, according to Mr. Hull.†

For the raised beaches of Great Britain reference will be made to the papers by the following authors: Ansted, Chambers, De la Beche, A. Geikie, J. Geikie, Godwin-Austin, Prestwick, Richardson, Trevelyan.

The literature on Scandinavian ‡ raised beaches is extensive, and there are many fine examples of fading elevated shorelines upon that coast. The features do not show distinctly enough upon the topographic maps for purposes of illustration.

Old beaches at various levels above the water of Pechora bay in the Great Tundra region of northern Russia appear to be former shorelines. § Mr. Jackson does not mention less perfect terrace forms the further he went from the present shoreline, but he proved the progressive stages of uplift by the less perfect preservation on the more elevated beaches of the pine tree trunks, which he considers as brought down by the Pechora river.

There is a former shoreline near Ogunquit, Maine, and also farther to the northeast, upon which little work has been done since uplift.

There is an 800 foot cliff six miles east of San Roque point, Lower California, which should be examined in the field to determine whether it is a former sea cliff or not (H. O., 1268).

Another case suggestive of uplift is seen in Santa Rosalia bay, Lower California (H. O., 1100, 1193). The lack of more accurate information about this region makes it impossible to use it as surely showing uplift.

Cliffs 75 feet high are seen along the Sonora coast, Mexico, near the mouth of the Colorado river. They are so distinct as to indicate a recent elevation (H. O., 800).

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* See papers by Fairchild, Gilbert, Lawson, Leverett, Newberry, Schott, Spencer, Taylor, Upham, and Warren.

† Physical Geology and Geography of Ireland, 1878, 107; see also paper by Kinahan.

‡ See pp. 158–160.

§ F. G. Jackson, The Great Frozen Land, Macmillan & Co., 1895, 129, 262. Map.

Superposed Drainage. — No attempt has been made in this study to work out the sequential stages in the fading of elevated shorelines. This problem is intimately connected with the dissection of the land, and depends largely upon the factors which control such dissection in any given locality. The shore deposits being coarser would probably remain longer than those finer materials laid further out from the old shore. When however all the shore deposits themselves are eroded away, the amount of the former coastal plain overlap may frequently be inferred from the arrangement of the streams. Where there never had been a cover, the adjustment of the drainage to the structure would be more perfect than where the streams had taken consequent courses over an uplifted coastal plain. The coastal plain sediments would overlie uncomformably whatever structures happened to occur in the offshore region of the previous cycle, and thus the streams in cutting through the cover would have many chances to become superposed upon unexpected difficulties beneath.* The line between the region of well adjusted drainage and the region in which superposition of streams is found represents a former shoreline, now elevated and in a late sequential stage.

9. Islands.

Consumption by the Sea. — As a part of the sea's work to reduce all the land to a submarine platform just above wave-base, the islands formed by the depression of a region are some of the first forms to be demolished. Very small islets are quickly reduced to skerries and to submarine reefs. Large islands are more continental in character, and their coasts may become mature long before the islands themselves are consumed. These larger islands are not as a rule tied to the mainland by bars. But islands, which range in size from an area of one third of a square mile up to some two hundred square miles, are very frequently tied to the mainland by bars in the process of their demolition by the sea.

Upon the coast of Italy where island-tying in its various stages is beautifully shown, such a bar is called a tombolo.† For convenience in distinguishing island-tying bars from those of other kinds, the writer proposes to call every bar of this kind a *tombolo,* giving an English plural tombolos.

Loop-bar: Shapka, Figure 12. — An island at some distance from the mainland may be so large that the sea cannot dispose of all the detritus

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* See fuller statement by Professor Davis, Lond. Geog. Jour., 1895, V. 128–138.

† See Figure 16.

worn from the island, and then in youth this waste tails off on right and left toward the mainland or in the direction of the quietest water. If the island is so far from the mainland that these spits cannot reach land, they are most likely, in swinging back and forth with varying currents, to join each other and thus form a loop-bar.

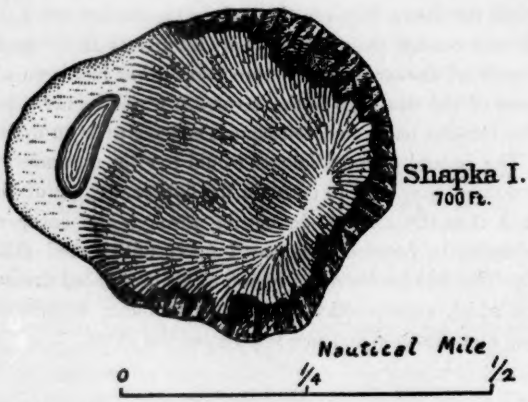

FIGURE 12. Loop-bar: Shapka Island, Alaska.

The form of Shapka island, Alaska (Figure 12), indicates that it had two spits formed on its lee side from the waste of the eastern cliff face, and that these two have now joined, forming a looped bar enclosing a lagoon (C. S., 8881).

Cup butte, Utah, is an example in the fossil condition.*

San Juan Nepomezino island, Lower California, has a salt lagoon at its southern end evidently similarly inclosed (H. O., 42).

Cockenoes island has two long stringing bars pointing toward the coast at Norwalk, Conn., but the bars have not as yet joined (C. S., 116, 3039).

Endelave island (Denm., Bogense) is being consumed on the east and south sides and the material is transported around the north and west ends. This is shown by the hooked spit on the west end and by the five lines of slashes, or narrow lagoons, inclosed by successive outgrowing beaches. If this process is continued a little farther we shall here see another Shapka island with enclosed lagoon.

Flying-bar: Sable Island. — When an island is completely reduced to a submarine condition, the bar formed from its waste may still remain. A case like Shapka, when the former island was completely consumed, would give a flying-bar.

* Gilbert, Lake Bonneville, p. 55, Pl. VI.

Sable Island, composed of unconsolidated materials, is rapidly disappearing.* The map shows an enclosed lagoon, which was formerly nearly twice its present length.† Its form and structure suggest that it represents a flying-bar, after the island, from which its materials were derived, had been completely destroyed.

Simple Cases of Island-tying and their Stages. — One of the features of shore development following depression which shows in most clear and decisive terms the relative time since depression, is the formation of tombolos connecting islands with each other and with the mainland. When the sea is able to do the work given it to perform, shore-grade is established and littoral transportation occurs along the base of the cliffs, which are cut on the more exposed portions of the island and mainland, and deposition begins along the edge of the currents in the comparatively dead water. Such dead water naturally occurs upon the protected side of the island between it and the mainland, and a tombolo is begun usually upon that side. According to the direction of transportation the bar may grow from the island, from the headland, or from them both. The essential point to bear in mind is this: the currents will seek to alter the shoreline better to satisfy their conditions of work.

Numerous examples from various localities are given of the seven stages into which island-tying has been divided. The lists under this and other headings of the present article are however not at all exhaustive, enough examples being given in each case to bring out the successive stages of development and to show the play of the variable elements within the limits of each stage.

I. *Initial Island* (Birth): *Austria; Sweden.* — The first stage in the life of an island is where no work whatever has been done upon it by the sea. Great variety of form and size will occur, depending largely upon internal structure and pre-natal development. The longitudinal structure of Austria, the transverse structure of Casco bay (Figure 1), and the concentric structure shown on the Vaxholm sheet of Sweden, give markedly different island forms. The mature dissection of Scandinavia gives many small islands, while the more youthful dissection in the Puget sound region shows but few islands, and these much larger.

II. *Nipped Island* (Infancy): *Sweden; Maine,* Figure 1. — The sea first attacks the coast and makes a nip all around the island, but cuts more upon the exposed side. The sea at first can dispose of all the waste from the island.

* Patterson, Trans. Roy. Soc. Can., 1894, XII. (2) 1–50. Map.
† *Loc. cit.*, p. 37.

Many islands along the east coast of Sweden (Swe., 11, 17, 22, 29, 37, 46, 67, 68, 76, 85, 86, etc.); also on the west coast (Swe., 18, 24, 25, 32, etc.).

Maine (C. S., 101, 102, 103, 104, 105, 106).

Numerous examples on the coast of Norway (Nor., 5, B; 48, B; 49, C; etc.).

Many islands among the Orkney, Shetland, and Hebrides on the north and west of Scotland (Scot., 58, 59, 101, 104, etc.).

Off Marseilles (Fr., 247) there are several very young islands.

Lipari islands, Tyrrhene sea (Ital., 244).

Capo Passero island, Sicily (Ital., 277).

Gemini and Corbella, south of Elba (Elba).

Islands west of Fosana, Austria (Austr., 26, IX).

Numerous islands in the Adriatic where ideal possibilities for future tying exist (Austr., 31, XIII, XIV; 34, XVII; etc.).

III. *Uncompleted Tombolo* (Youth). — When more waste is supplied than the sea can deposit offshore, transportation alongshore begins, and there is a tendency to aggrade the surplus load of detritus. Such building would naturally be expected to occur in the comparatively quiet water between the island and the mainland. This is found to have taken place in many localities. According to the several conditions of the variable factors in the problem, the tombolo may begin to grow from the mainland, the island, or from both.

a. *Attached to Mainland only: Gigha.* — The typical example is seen on the west coast of Scotland, where Rhunahaorine point projects as a cuspate foreland from the mainland toward the island of Gigha (Scot., 20). This foreland is of the nature of the tidal forelands described on page 214, and a tombolo may never be completed across the deep channel.

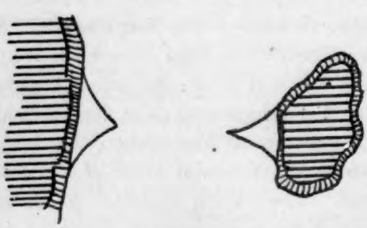

FIGURE 13. Diagram of Uncompleted Tombolo.

A shoal extends from the large island, Berneray, toward the rocky stacks, Sgeir a' Chail (Scot., 89). This islet is fast being consumed by the sea, and probably never will be tied.

Lingay strand extends below high tide level toward Lingay island (Scot., 89).

Callao, the seaport of Lima, Peru, is built on the tombolo growing toward San Lorenzo island (Stieler, 94; Middendorf, Das Küstenland von Peru, 1894, 36).

Angel island in San Francisco bay, California (C. S., 5581).

b. *Attached to Island only: Tunö.* — From Tunö island (Denm., Samsö) there projects toward Samsö island a lanceolate cusp, showing the attempt to tie the smaller to the larger island.

Another cuspate foreland projects from Taransoy island toward Harris island (Scot., 98).

Vigso island has two curved spits not quite able to reach the mainland (Denm., Saxkjöbing).

c. *Attached to Mainland and Island: Aebelö;* Figure 13. — A bar is forming from Aebelö island and from a smaller island close to the mainland (Denm., Bogense).

Another example is Spectacle island in Boston harbor (C. S., 337), where the "nose-piece" of the spectacles consists of two cusps almost joined. Upon the Coast Survey chart these two islands are not joined, but in 1896 the writer saw from a steamer that the tombolo was completed.

Between Pabbay and Berneray islands a tombolo has begun to grow which consists so far of a cuspate projection from each island (Scot., 89).

The tombolo connecting North rocks with the Irish coast (Ireland, 49, 50) is not completed, and it is very probable that these rocks will be completely consumed before tying on is accomplished.

The flats between Barra and Fiaray islands represent the attempt of the sea to tie islands together (Scot., 58, 59, 68, 69). The flats surround three other islands.

Tombolo growth is indicated from both Ibiza and Formentera islands, the advance from each island being made toward the other (Spain, Bol. VII, Lám. B). There are several small islands in the line of probable future growth, which will be surrounded by the completed tombolo.

Marrowstone island, Washington, at present is detached from the peninsula to the west, Kilisu harbor having communication across the bars at both its northern and southern ends (C. S., 6450 and 647).

Several of the islands in Sitka harbor, Alaska, are soon geographically to become land-tied; as, for example, Cannon island, Beardslee islands, and The Twins (C. S., 725).

Isla de Ápies, Mexico (H. O., 878), is now connected at low water.

Rush and Ackerman islands, Costa Rica, are nearly in this stage (H. O. 1028).

Redonda and Siriba islands, Brazil (H. O., 486).

A tombolo largely of mechanical construction though there is some coral growth in it, is attempting to connect Ceylon with the mainland.*

IV. *Completed Tombolo* (Adolescence). — As a rule when islands along a stretch of coast are completely tied to the mainland by tombolos, the coast as a whole is graded, and may be regarded as in adolescence. Occasional youthful features will persist after the region has reached adolescence, and in the same way completed tombolos will sometimes be found where the other features of the coast are indicative of youth. There are three classes of tombolos: single, Y-shaped, and double.

a. *Single Tombolo: Nahant,* Figure 14. — Nahant is tied to the Massachusetts coast at Lynn by a single tombolo, which is typical, with the exception that the island itself is made up of Big and Little Nahant, which are themselves joined by a tombolo.

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* Map by J. Walther, Pet. Geog. Mitt., Erg. 102, 1891.

Many other cases of single tombolos occur in Boston harbor (C. S., 337; G. S., Boston Bay, Mass.). Among these may be mentioned Winthrop head, point Shirley, Peddocks island, Hull, and the islands tied by Nantasket beach.

Little Koniushi island, Alaska (C. S., 8881).

FIGURE 14. Single Tombolo: Nahant, Massachusetts.

Biorka island, Alaska, is made up of two islets tied together by a bar (C. S. 724).

George island, Alaska, shows composite building (C. S., 741).

Amaknak island, Alaska, has three component parts (C. S., 8901).

Morro Ingles island, Paz point, and San Vicente island, Mexico (H. O., 640).

Marc island (C. S., 5524, old number 625) is a case in San Pablo bay where an island has been tied by a tombolo to the mainland.

Spider island, Alert harbor, Chile (H. O., 926).

Mt. Division, 1880 feet high, is connected with the mainland of Peru by a low sandy isthmus (H. O., 1178, 1185, 1162), which is probably a tombolo.

Morro of Barcelona, Venezuela (H. O., 374).

An island off the Bonneville shoreline near George's ranch was tied by a tombolo, in which three attempts at tying are figured by Mr. Gilbert.*

Gilsay island in the sound of Harris (Scot., 89).

Taransoy is apparently built up of three islands tied together (Scot., 98).

Howth peninsula has the form of an island tied to the mainland northeast of Dublin (Ireland, 112). Transportation is indicated both from the cliffs of the mainland toward the island and from the island along the tombolo. Broad tidal flats, cut with runways, occur on the right and left of the tombolo.

Mweenish island is made up of three drumlin-shaped portions connected by narrow necks, presumably tombolos (Ireland, 115).

Illaunatee or Straw island, one of the Aron islands (Ireland, 113).

The Chesil bank † connects the isle of Portland with the mainland of Dorsetshire (Eng., 17).

* Mon. I., U. S. G. S., 113, Fig. 23.

† For the literature on this tombolo consult De la Beche, Geol. Notes, 1830, II. p. ix; Geikie, Textbook, 3d ed., 1893, 451.

The rock of Gibraltar (Q. J. G. S., XXXIV., 1878, Pl. 23; Brit. Ad., 144, 1448) was an island, and is now tied.

Sermione, Italy, is on an island in Garda lake connected by a bar three kilometers in length, three times the length of the island (Ital., 48).

Cape Milazzo (Ital. and Sicily, 253).

Penisola Magnisi, and that on which Augusta is built (Ital. and Sicily, 274).

Monte Enfola (Elba).

The peninsula southwest of Vari, on which Zoster cape is situated (Attica, VIII).

Koroni (Attica, XI).

Probable tying of islets to Samsö island (Denm., Samsö).

Faejo island is composed of two parts tied with a tombolo (Denm., Saxkjöbing).

Knudshoved point (Denm., Saxkjöbing).

Bogo island has Farö tied to its northwest point by a long tombolo (Denm., Vordingborg).

Avernak island (Denm., Faaborg).

Drejo island is composed of two tied by a narrow tombolo (Denm., Svendborg).

Two or three islands were apparently tied together to form the hook north of Aeröskjöbing (Denm., Svendborg).

b. Y-tombolo: Morro del Puerto Santo, Figure 15. — The type of the Y-tombolo, where one bar from the island unites with two from the mainland, is found in Puerto Santo bay, Venezuela (H. O., 374).

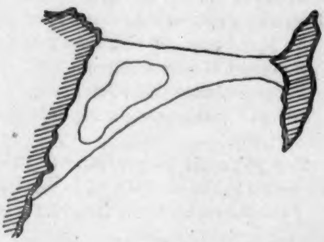

FIGURE 15. Y-tombolo: Morro del Puerto Santo, Venezuela.

Northeast point on St. Paul island, Alaska (C. S., 8990, old number 886) is connected by a Y-tombolo enclosing a lagoon.

Mahedia, Tunis, is figured by Reclus as tied in this manner.*

Nicolaos (Attica, XVII).

c. Double Tombolo.—If the island is comparatively near to the mainland, and if it has considerable extension alongshore, there will generally be formed a tombolo from either end, enclosing a lagoon. Aebelö and Nahant are too far from the coast to have a double tombolo, but Marblehead neck and Monte Argentario (Fig. 16), are near enough and large enough to have a bar at each end.

(1) *Only one Bar completed: Marblehead Neck* (C. S., 335). — Only one bar is here built, and that in recent geographic time, for the shore is not graded outside of the tombolo, either on the right at the southern end of the island, or on the mainland at the left. The tombolo has probably been built largely from the bottom, since both ends form nearly a right angle where they join the island and mainland.

Stony island in lake Ontario, New York, is composed of two islands, probably drumlins, joined by a bar at the southern end, while a second bar is nearly completed at the northern end (G. S., Stony Island).

The island east of Port Townsend, Washington, is joined by one bar at the head of Oak bay (C. S., 6405).

* La Terre.

Bodega head, California (C. S., 630), appears to be an island tied to the mainland by a bar, probably broadened by elevation since it was built and now having its surface much diversified with dunes. A second bar is almost completed, a spit extending from the mainland nearly across Bodega bay. Bodega head like Tomales point to the south is of resistant granite,* east of which the longitudinal valley, now shown by Bodega and Tomales bays, was carved in the weaker sandstones, along a probable fault according to Professor Lawson.

Point Galero, Mexico, is tied by San Juan beach, and a second bar enclosing Chacahua lagoon is being built (H. O. 935).

Copenhagen is apparently built upon a bar connecting Amager with Seeland, and the buildings and fortifications of the city have much altered the former appearance of the bar, harborage being gained by maintaining water communication across the tombolo (Denm., Kjöbenhavn).

Helnes island is joined by a bar at its northern end (Denm., Vissenbjerg). Overlap, offset, and stream deflection all indicate a current from the right, so that the tombolo probably grew from the island to the mainland.

A small island south of Faaborg (Denm., Faaborg).

Several cases along the east shore of the Cattegat (Swe., 18, 24, 32, 41, 51, 61).

Kekenis is tied to the larger island of Alsen and the second tombolo is now beginning as a spit on the other end of the island (Germ., 24; Denm., Faaborg).

An island north of Glücksburg in the Flensburger fjord (Germ., 23).

Halbinsel Wustrow (Germ., 85).

Pulitz is almost tied (Germ., 64).

Several islands are strung together at the southeast point of Rügen island (Germ., 64).

Eye peninsula is apparently tied to Lewis island (Scot., 105), but rocky ledges are shown in the tombolo, and separation may never have been complete.

Vatersay island in the Hebrides is composed of two high portions connected by a lower neck (Scot., 58).

Peninsula point, California (C. S., 5581), is tied by one bar and a second is nearly completed.

Conanicut island (C. S., 353) in Narragansett bay is made up of two portions joined by a bar.

(2) *Both Bars completed: Monte Argentario,* Figure 16.—Monte Argentario, Italy, is an instructive example in explaining the method of tying islands.

In the interior of Orbetello lagoon a bar extends from the mainland toward the island. This tombolo was probably the first built, from the mainland to the point where the village of Orbetello now stands. Meanwhile a bar further north, *Tombolo della Giannella,* was growing from the mouth of the Albegna river toward Monte Argentario. At a little later stage shore-grade was established along the southeast coast of the island and the *Tombolo di Feniglia* grew toward the mainland. The growth of this third tombolo prevented the extension of the Orbetello tombolo.

The reasons for the above interpretation are as follows. The tidal inlet across the Tombolo della Giannella is close to the island while that of the Tombolo di Feniglia is next to the mainland. With such simple bars as these are, where there

* J. D. Whitney, Geol. Sur. Cal., 1865, I. 84, 85.

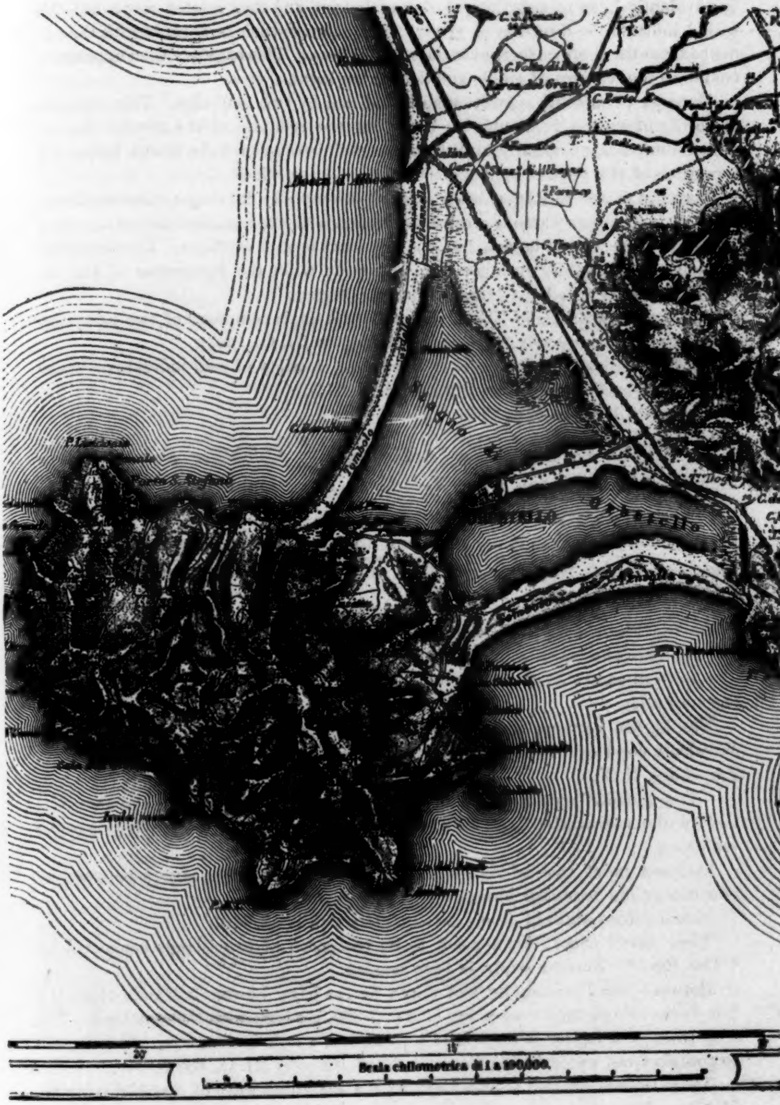

Figure 16. Tombolos: Monte Argentario, Italy.

has evidently been no complete closing of lagoon and then a later reopening, this would indicate the direction of growth, particularly when it accords with the evidence from the shore curves, as it does in this case. This example then apparently combines the features of single and double tombolos.

Monastir (Tunis, 57) is built on an island tied by two tombolos. This example is worthy of special field study to bring out the relations of the several uncompleted tombolos, apparently built from the mainland toward the island before the formation of the present tombolos which enclose the others.

Jasmund is tied to Rügen island by two beautifully curving tombolos (Germ., 42, 64). At Lietzow there is a third connection with the mainland across a narrow portion of the enclosed lagoon, but this in part at least is artificial. Transportation is indicated as slightly stronger from the right, while the squareness of the bar suggests that it was built largely from the bottom.

San Juan Nepomucino island, Lower California, is composed of two parts connected by bars completely enclosing a salt lagoon (H. O., 1223).

Margarita island, off the coast of Venezuela, consists of two individuals joined by two bars enclosing Laguna Grande (H. O., 374).

Presqu'ile de Giens (Fr., 248).

V. *Lagoon-marsh-meadow* (Adolescence): *Colchester Point.* — After formation of a lagoon by a Y-tombolo or a double tombolo, the wind blows in sand from the beaches and streams, and tides deposit silt, so that in time the lagoon is converted into marsh and the marsh in turn into meadow, if the island is not first consumed by the continued attack of the sea.

On the Plattsburg, N. Y., sheet of the Geological Survey, at Colchester point, Vermont, are two cases of filled lagoons, each having an almost extinguished pond. The western pond still maintains connection with the lake, while the eastern pond has no outlet.

The lagoon between Cumberland head and the mainland is two thirds filled, Woodruff pond overflowing across the last built bar into lake Champlain (G. S., Plattsburg, N. Y.).

"The Bonnet" on the west side of Narragansett bay appears to be an island tied to the mainland (C. S., 353). Wesquage pond is the lagoon between the tombolos.

Sachuest point, east of Newport (C. S., 353, 3044), has the lagoon between its two connecting tombolos almost completely filled.

Monte Circeo south of Rome is completely tied (Ital., 170).

Tiree island (Scot., 42) appears to be composed of two islands connected by "The Reef." Further study is here needed.

Between San Francisquito and Santa Teresa bays, Lower California, there is a low dune-covered tract connecting land 300–600 feet high with the mainland. The only trace of a lagoon is the bed of a pond, half a mile in diameter, which is said to contain fresh water during four months of the year (H. O., 638).

Three islands are tied together and to the mainland west of Sacrificios island, Mexico. Two of the lagoons are completely filled, and the third one is more than half filled (H. O., 875).

The lagoon between the three or four individuals of Santa Maria island, Chile, is completely converted into marsh (H. O., 1209).

Alki point, Washington (C. S., 651; G. S., Seattle). This point may never have been separated from the mainland.

The northern portion of Unalashka island from cape Kalekhta to Constantine bay, Alaska, has been tied by two bars to the main island. The enclosed lagoon is a long narrow one, extending the whole distance between the bars. The map indicates considerable filling on the sides of the lagoon (C. S., 821).

Massoncello point, Italy, upon the southern end of which Piombino is situated, is an example where the enclosed lagoon has been completely aggraded by a river delta, that of the Cornia River (Ital., 119, 127).

VI. *Vanishing Island* (Adolescence). — After an island has become land-tied, it continues to waste away by the action of the sea and subaerial forces, until a stage is reached when the island is gone and nothing but the tombolo which connected it to the mainland remains. This stage must of necessity be a short one, for the unconsolidated tombolo will be rapidly consumed. This feature would be one of late adolescence. Theoretically we should expect to find single, Y, cuspate, and double tombolos remaining after the islands had been consumed. The three examples which appear to be surely in this stage are all cuspate. This form is probably the one which best resists the sea, and each of the others is easily converted into the cuspate.

Cuspate Tombolo: Block island, Figure 17. — The type cusp whose position has been determined by a former island is Sandy point, Block island (C. S., 356).*

At the southern end of Revere beach (C. S., 337; G. S., Boston Bay, Mass.) there is a cuspate projection where a drumlin was formerly tied on and has now been consumed.

Uvita point on the western coast of Costa Rica (H. O., 1035) is a cuspate foreland whose position is apparently determined by rocky islets off the point. This seems to be a case where the cusp is completely tying the island when the island itself is practically destroyed.

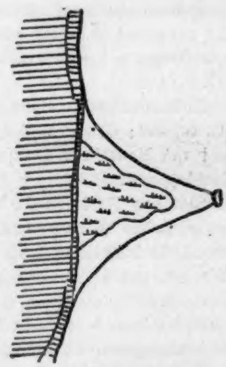

FIGURE 17. Vanishing Island; Diagram of a Cuspate Tombolo. Similar Stage found in Sandy Point, Block Island, Rhode Island.

VII. *Straight Coast* (Maturity). — The mature stage of island-tying is where the islands and their connecting tombolos are completely consumed

* See Livermore's History of Block Island, 1877, 175.

by the sea. Therefore the straight coasts of Jutland, Italy, etc., as given on page 246, are the forms of the stage next succeeding that of the vanishing island.

Complex Cases of Tying. — Many of the actual examples of island-tying are not simple. A great variety of combinations occur in nature, but only three will be here considered, viz. where several tombolos unite a group of islands, where rivers surround islands with their waste, and where slight movements of the land have assisted tying.

Samsö Island is composed of two higher portions joined by a lower narrow neck (Denm., Samsö). The central portion of this neck is heath and forest, presumably overgrown marsh, bounded on either side by gently curved shores. These curves also indicate tying and complete filling, for the coast farther north and south has not such smooth outlines, indicating that the present position of the land has not been maintained for a time sufficiently long to develop such curving shorelines. The left hand end of the eastern bar is complicated on account of numerous small islands.

Three islands in Lenox cove, Tierra del Fuego (H. O., 455[c]).

West of Magdalena bay an island between cape Corso and Entrada point is tied to another island at cape Lazaro (H. O., 621, 644).*

Marambava mountain, 2066 feet high, has a twenty-mile tombolo extending to the mainland of Brazil, which close to the shore is broken by a tidal opening. A spit from the tombolo inside of Sapetiba bay is growing toward Jaguanao island (H. O., 488).

In Boston harbor there are three groups of islands tied by numerous tombolos (C. S., 337; G. S., Boston, Boston Bay, Mass.), viz. the Winthrop, the Quincy, and the Nantasket groups. Marshes occur in all three, indicating adolescent development.

Sidi bon Said (Tunis, VII, VIII, XII, XIV, XX, XXI) is on an island which is tied to the Tunis mainland by three bars. The central one is 5 to 8 kilometers broad, 10 kilometers long, and has an elevation in places of 10 or 12 meters. Whether this broad isthmus was originally two tombolos enclosing a lagoon, or was made land by elevation, is not certain from map inspection. Later, however, two tombolos have been built from either end of the island, enclosing between them and the earlier built isthmus two lagoons, Sebkhat er Riana and Lac de Tunis.

Leucate (Fr., 255) is an island of Oligocene strata, tied by one tombolo to the mainland, and has also a wing-like bar on both the right and left sides. These wing-bars are built up from the bottom in large measure, according to the indications given by the right-angled abutment of the left end of the right bar against Leucate, and a similar abutment of the left bar against the older land near Port Vendres (Fr., 258). The stream deflections indicate alongshore motion to the right, which is also suggested by the offset of the right wing-bar by the left.

The island of Cette (Fr., 233), of Jurassic strata, is tied by the wing-bar from the left side of the Rhone delta. To the southwest the volcanic knob of Agde is more

* In regard to dislocation as a probable cause of these islands, see W. Lindgren, Proc. Cal. Acad. Sci., 1888-90, I. 173, II. 1, III. 26, and references there given.

completely surrounded by the aggraded detritus of recent times (Fr., 244, 245). The latter may never have been an island.

Berneray island in the Hebrides is made up of several higher portions connected by sandy areas (Scot., 89).

A group between Brandon and Tralee bays (Ireland, 161).

Eddy island is a composite island, in which there are two examples of lagoons almost included by tombolos (Ireland, 114, 115).

Several islands at the head of Galway bay seem to belong to this class (Ireland, 115).

The type of islands tied to the mainland by delta growth is seen in lough Swilly (Ireland, 11), where Inch Top island, 732 feet high, appears to be joined to the mainland on the east side of the bay by the detritus borne down by the small streams. Other knobs to the southeast of Inch Top hill were possibly tied in a similar manner.

The islands of Paleozoic, Mesozoic, Tertiary, and eruptive rocks are surrounded by the delta deposits of the Danube (Taf. III. Jahrb. k. k. Geol. Reichs., XL., 1890).

From San Pablo point to Richmond point is an island completely joined by marshland (C. S., 5581). In this case streams have evidently aided the tidal currents in filling in between a former island and the mainland.

North head, McKensies head, and various other islands at the mouth of the Columbia river (C. S., 681*, 640), are seen upon inspection of the more detailed charts and Mr. Davidson's sketches * to be tied together to form cape Disappointment, which is in turn tied to the mainland at Chinook point.

An example in which slight elevation may have helped island-tying is seen at the mouth of the Medjerda river (Tunis, VII, XIII, XIV, XX).

Öland and Gjol are becoming land tied by river and tidal deposits, probably more tidal than river, since the elevation of the land from which the streams come does not exceed 75 meters (Denm., Nibe).

An example of complex island-tying is seen on the chart of San Quentin bay, Lower California (H. O., 1043). It would appear that the earliest tying was done when the land stood lower than at present, for some of the bars outside of the salt lakes are cliffed.

10. Bay-bars.

An Adolescent Feature. — Shore development of a submerged region has been studied as regards island-tying; a second important feature is now to be considered. It has been shown that when shore-grade is attained detritus will be transported along the beach at the foot of cliffs, and tombolos connect many islands with the mainland. As the headlands are attacked faster than the bay heads on account of their more exposed position, wing-bars will frequently be formed of the detritus from the cliffs. This special form of bay-bars will be considered under Winged Beheadlands.†

* Pacific Coast Pilot, 1889, 451.

† See page 213.

The sea also erodes the bottom and supplies material for the bar. The proportion of bottom to side supplied detritus will vary exceedingly. With a deeply dissected, steep coast, the proportion of material from the headland will be large, while in a slightly drowned region, developed to past-maturity in the previous cycle, there will be more material under water above wave-base, and therefore a greater proportion of bottom detritus. There are so many variables which enter into this problem, — viz. initial form, prevailing winds, strength of currents, height of tides, radius of curvature of eddies, structure of land, etc., — that it is difficult to predict where a bar will be built across a bay. It may be said, however, that the sea is not satisfied with an irregular shoreline, and in its attempt to reduce the land to a submarine platform it will straighten the shoreline in order better to attack the land. The curve that a given shore will take depends upon the forces acting at that point.

In one place wings will extend from the projecting headland, in another the currents will build a bar across the mouth of the bay, in a third the bar will grow from a point between headland and bay-head, while in a fourth place the alongshore action may be so weak or the bay so broad that the sea will begin to fill at the head. In this fourth case any delta filling will go on at the same place as the accumulation by sea action.

When the bay-bar is completed, and there is transportation of material practically all along the shore, shore-grade is attained, and the period of adolescence in shore evolution is reached. The narrow and broader bays behind the bars are gradually filled by river, tide, and wind. Where the river activity is strong enough, it pushes a delta beyond the bar. Maturity is reached when the bays are filled and the headlands cut back so that the initial shoreline is lost. From this time forward the sea, satisfied with the shore curves, eats farther and farther into the land with the intention of reducing all that stands above wave-base to a monotonous submarine platform.

The classification of bay-bars here given is not a satisfactory one. The separation into stages of development is only partial, for more facts of observation are needed. The location of the bar in the bay, which depends upon the ratio of alongshore to on- and offshore currents, as well as upon the form of the bay, has been used to make three types of bay-bars. Under each of these, stages of filling occur, all centring about the attainment of shore-grade, and therefore bay-bars may be limited as a class to a period extending from late youth to early maturity. Bay-bars are characteristic of adolescence.

A. *Bar across Mouth of Bay: Lake Ontario,* Figures 18, 19. — Several bays on the eastern shore of lake Ontario are closed by bars, whose form indicates more bottom than alongshore action, there being

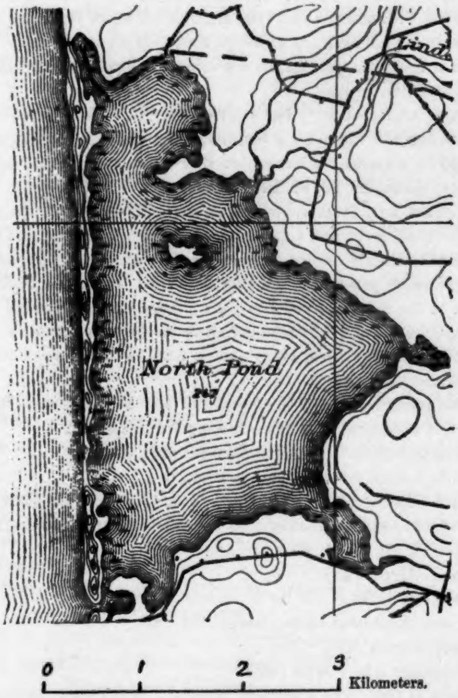

FIGURE 18. Bay-bar across Mouth of Bay, Lake Ontario.

no dominant offset and overlap. This indication is confirmed by the observations of the currents, many of the courses of observed bottle drifts having ended on these bars.*

Instead of looking at these sandbars as barriers to keep the sea out of the bays,† let us regard them as built by the sea in order to prevent the wasting of its force dashing into the indentation, where the delta growth will finally be victor, and in order that the sea may be able to concentrate

* Surface Currents of the Great Lakes, U. S. Dept. of Agriculture, Weather Bureau, Bull. B, Washington, 1895.

† See Geikie, Scenery of Scotland, 1887, 186.

its force upon the more exposed coasts, by having a simpler coastline upon which to work.

(1) *Bay but little filled* (Youth-Adolescence). — Bay-bars are forming across three bays on the Oldenburg sheet (Germ., 60). Two of these are on the southern side of Fehmarn island and the third is south of Grossenbrode. In Orther bay transportation is from the left, but in the other examples it is about equally from right and left headlands.

Gruber bay is enclosed by a bar (Germ., 60, 84). The deflection of the outlet, Dahmer-See, to the left indicates a dominant current from the right.

Stettiner bay is closed by a bar which shows a very beautiful series of aggradation shorelines (Germ., 89, 90, 91, 92, 120, 121, 122, 154, 155, 187). The dominant current is indicated by offsets, overlaps, and stream deflections to be from the left. The contest between river and tidal currents on the one hand and alongshore current on the other is clearly shown. A study of details on the ground in connection with these expressive general maps ought to bring out many features of the progressive steps in the formation of bay-bars. Islands are included in this bar and thus complicate its form. Usedom island is made up apparently of several individuals, and Wollin island is in large part a portion of the drowned mainland and not the later built foreland.

Three bays formerly arms of Hochwachter bay are enclosed (Germ., 59). The indications are of a dominant current flowing from the left.

Several examples from Kiel northward (Germ., 39, 58).

Warnemünde is built on a bay-bar (Germ., 86).

Kurische and Frische bays (Germ., 1, 3, 8, 9, 15, 16, 29, 30, 48, 49, 50, 71, 72, 73).

Garder, Dolgen, Leba, Sarbsker, and Zarnowitzer are enclosed to form lakes or lagoons (Germ., 25, 26, 44, 45, 46).

Vietzker lake (Germ., 43).

Vitter lake (Germ., 66).

Jamunder and Buckower lakes (Germ., 65).

Kamper lake (Germ., 93).

Horst-Eiersberger lake (Germ , 92).

Bankel-damm is shut in by a bay-bar (Germ., 13). Transportation is about equal from right and left according to the map indications.

Schlief-see is closed by a bar growing from the right, for on that side the curve of the cliff is continued in the line of the bar, while on the left the bar abuts abruptly against the oldland, forcing the stream under the left hand bluff (Germ., 13).

The Sejrslev headland has a right and left wing growing across bays (Denm., Lögstör).

A cuspate bar extends from the left hand side of Horsens fjord toward a rock near Alro island (Denm., Skanderborg).

Across the mouths of some ten drowned valleys, between the Dnieper and the Danube rivers on the Black sea, bars have grown (Rus., 33; Atlas Univ., 38). More than half of them are completely closed by the sea action. The low mean annual rainfall in this region, 15.83 inches at Odessa,* would cause weak stream

* E. Loomis, Contributions to Meteorology, revised ed., 1889, 151, Pl. XXIII.

action. The waves and currents, though weaker on the inland sea than on the open ocean, are relatively stronger than the streams, for they are able to close these bays. The absence of ocean tides, which tend to keep open inlets into bays, aids this shutting up.

Across the western end of the sea of Azov a bar has been formed (Atlas Univ., 38; Rus., 48, 62) which has nearly rectangular junctions with the mainland, indicating that it has been built largely from the bottom of the sea.

Lituya bay, Alaska, has the right spit offsetting the left. Glaciers now descend to sea level in various arms of this fjord (C. S., 8451).

Thomas bay, Alaska, has bar forming between Vandeput and Wood points (C. S., 733).

On Amaknak island, Alaska, the spit has grown southward from Ulakhta head more than half way toward Rocky point (C. S., 821).

Coburg peninsula west of Esquimalt roadstead, Vancouver island (H. O., 1306).

Tomales bay, California (C. S., 631), has a bay-bar extending three quarters of the way from the left toward the right side of the bay, thus indicating a dominant current from the left.

Willapa bay, Washington (C. S., 6185), shows incurving spits at the end of the bar, pointing up the river.

(2) *Bay more or less filled* (Adolescence), Figure 19. — Silting up of the bay enclosed by a bar progresses rapidly, as engineering works testify. Streams, tides, and winds fill this quieter water with waste. The changing conditions of alongshore transportation will be shown by the advance or retreat of the shoreline of the bay-bar.

A bar has grown from the right across the mouth of Mobile bay (C. S., 187, 188). Successive positions of this bar are indicated by some eighteen sympathetically curving dune ridges with intervening stream or marsh. The offset here indicates a dominant current from the right.

Tampa bay, Florida (C. S., 176, 177), shows overlap from right to left, thus indicating a dominant current from the right.

The overlap of the right bar at the mouth of the harbor of Rio Grande do Sul, Brazil, indicates a prevailing current from the right (H. O., 1191).

A bar is built from Palmia point to Gorda point across the drowned valley of San José river, Lower California. Its southern point overlaps and offsets the northern portion, indicating a current from the left (H. O., 635).

Several bays on Monte Gargano, Italy, show nearly complete filling (Ital., 157)

South of Söby on Årö island Vidsö bay is closed and the lagoon is considerably filled with marsh. A nip decreasing in height toward the bay-head is clearly shown on the German map (Germ., 24; Denm., Faaborg). These two surveys differ decidedly as to the amount of filling.

On the eastern side of the southern point of Falster island (Denm., Gjedser) the sea has a curving shoreline of large radius upon a low sandy coast behind which lies an enclosed lagoon, to the west of which is an area of higher land. The offsets and stream deflection indicate a prevailing current from the right Bötonor lake has a bordering belt of marsh, and there are other patches of marsh between this lagoon and the eastern shore. All the above facts suggest the growth of a bar across the mouth of an open bay. In front of the artificial sea wall, built to protect the coast, the map shows a belt of sand, as if the sea was even now building out in places.

On the western coast of Langeland and at the southern point are several enclosed bays partly filled (Denm., Svendborg, Gulstav). The offsets indicate movements in both directions.

The bays on the southwest side of Chirikof island, Alaska, show several stages of filling (C. S., 9191, old number 796). The sea built five bars from headland to

FIGURE 19. Nearly Mature Filling of Bays.

headland, in swinging curves satisfactory to itself. In the broadest bay there still remain two lagoons, but the others are completely filled (Fig. 19).

Kiska harbor on Great Kiska island, one of the Aleutian islands, has three bays showing three stages of filling. In the central one there is a large lagoon completely enclosed, in the northern one a small lagoon remains, and in the southern one the area back of the bar is completely converted into marsh (C. S., 9191). The alongshore current is here probably from the left, witness overlap of bars to the right, and streams crowded to right side of bays.

(3) *Bay filled* (Maturity). — The last few examples in the previous section are as near to mature forms of this kind of bay-bars as have been found in the present study. Mature stages of bay-bars merge into mature ria-deltas so closely that one can hardly separate them upon the map. When the bay is filled, the stream mouthing in the bay will attempt to push forward its delta, and the shore form

then depends more upon the ratio between stream and current, than upon the attempt of the sea to bridge across the bay. The day of the bay-bar is over.

B. *Bar in Middle of Bay.* — The form of the bay or the strength and position of the currents may cause a bay-bar to grow from the side of the bay, at some point between the head and mouth of the bay. If the growth of the bar is due largely to alongshore action, a spit will extend from the side of the bay; but if the bottom action is dominant, the bay-bar will abut nearly at right angles against the coast of the bay.

(1) *Bay but little filled* (Youth-Adolescence). — Yakutat bay, Alaska, has a bar forming at point Turner, about half way between mouth and head (C. S., 8451).

Chignik bay, Alaska, has spit growing from right side of bay only (C. S., 8891).

Kachemak bay, Alaska, has spit grown about half way across from its left side (C. S., 766).

Salinas bay, Lower California, has a bar enclosing a salt pond into which there is little or no drainage (H. O., 850).

Inverness or Moray firth (Scot., 83, 84, 93, 94) has a spit growing from either side, of which the left one is considerably near the mouth of the bay. The Dornoch firth (Scot., 94, 103) has spits in similar positions.* The writer questions whether the position of these spits indicates a dominant current in these two bays from the left.

Hagios Nikolaos bay (Attica, XVII). Current probably from right.

The small bay, Hejlsminde, on the eastern end of the boundary line between Denmark and Schleswig is shut in by a bar whose curve is continuous with that of the coast to the north, indicating a current from the right. On the left side of the bay there is nearly a right angle between bar and coastline, indicating that the sea builds here mainly from the bottom (Germ., 7; Denm., Skamlings Banke).

(2). *Bay more or less filled* (Adolescence). — Marathon bay in Greece (Attica, XVIII, XIX). The former courses of the Marathon river and the overlap and stream deflection to the right indicate the prevailing current to be from the left. On the right side of the bay the bar abuts against the oldland forming nearly a right angle with Kynosura point. This fact indicates that the bar is built mainly from the bottom.

Mosvig bay (Denm., Skamlings Banke) shows a smoothly curved bar continuous to the right and left with the shore curves, indicating filling from either side. The dominant direction of alongshore current is indicated as from the right by the stream deflection to the left. Behind the bay-bar the lagoon is almost completely filled with marsh.

The sea has built Tent moor and Barry links upon the two sides of the firth of Tay (Scot., 49) and the rectangular junction of the bay filling with the bay sides indicates that the building has been done from the bottom. Deflection is toward the central channel, where the relatively strong tidal currents interrupt the formation of a typical bay-bar.

Dornoch firth is a similar example (Scot., 93, 94, 102, 103).

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* Geikie, Scenery of Scotland, 1887, 186, 187.

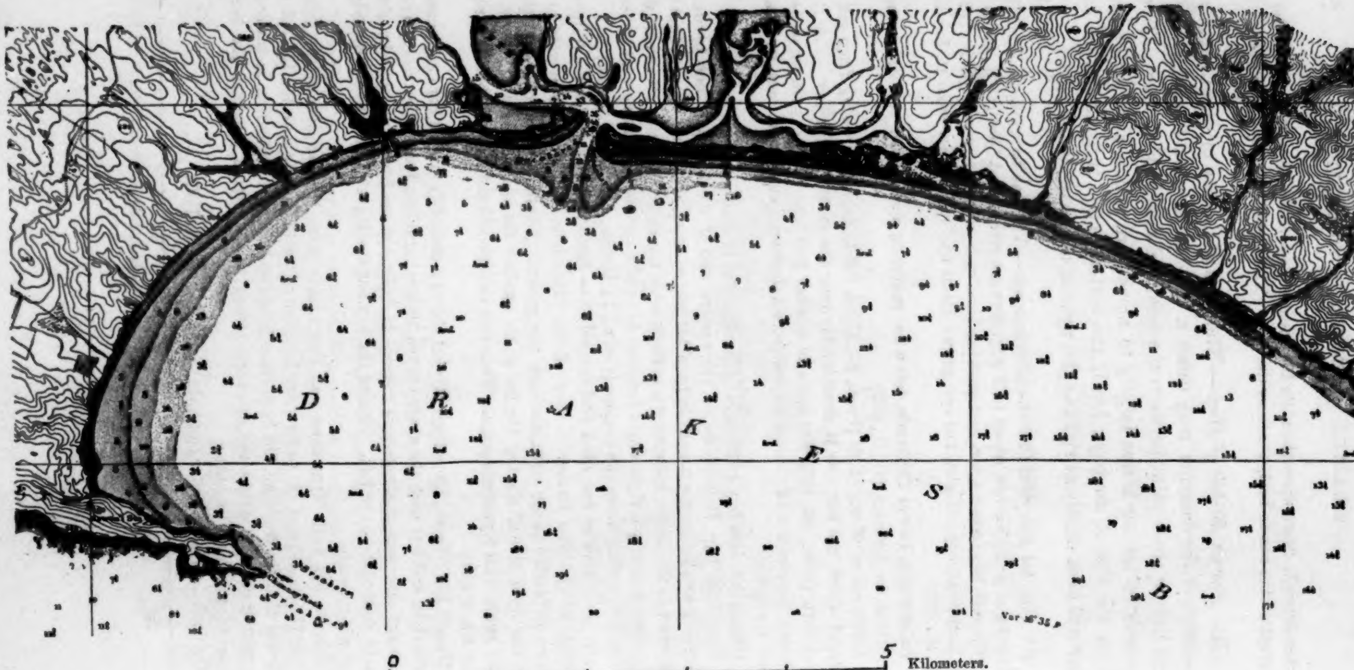

FIGURE 21. Bay-bar near Head of Bay: Drakes Bay, California. Nip in Drakes Estero.

(3) *Bay filled inside Bar* (Adolescence). — Under this heading are included several cases in which it is impossible to tell whether the bar originally was found where it now stands or whether it began near the bay head.

Procchio and Biodola bays (Elba).

The gulf of Salerno has a bar from Salerno across to Agropoli, inside of which it has been filled by river and tidal action, forming a rich delta plain with only a few remaining marshy places (Ital., 185, 197, 198).

Gulf of S. Eufemia (Ital., 241). Current from the left is indicated by deflection of streams to right.

From Palmi, Italy, across to Nicoteca a bar extends from the right headland to a point across the bay half way between the left headland and the bay head (Ital., 245, 246). Direction of current is probably from the right.

Bay of Phaleron southwest of Athens (Attica, III). The bar is largely produced by the action of the sea on the bottom, for the shore curves at its two ends are not continuous with curve of the bar.

Vari bay (Attica, VIII). This also shows sea bottom action.

Hanö bay (Swe., 6). Dominant current from the right.

C. *Bar near Head of Bay: Drakes Bay*, Figures 20, 21 — At the head of Skelder bay (Swe., 8) a bar is built chiefly from the bottom, since the bar curve abuts sharply against the two sides of the bay, and streams are deflected to the right on the right hand side and to the left on the left hand side of the bay, thus indicating currents in either direction from the centre (Fig. 20). There is evidence of very trifling transportation along the sides of Skelder bay.

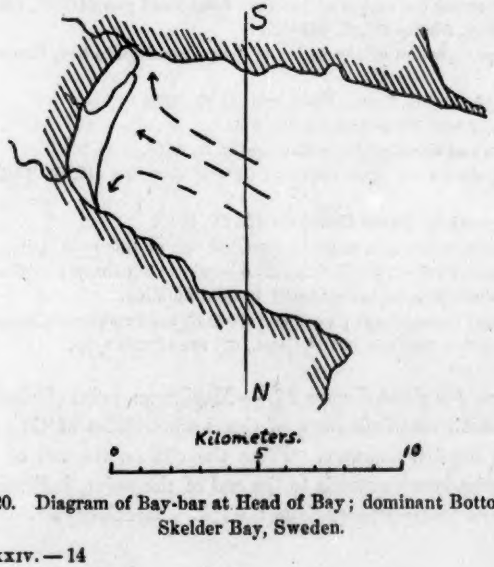

FIGURE 20. Diagram of Bay-bar at Head of Bay; dominant Bottom Action: Skelder Bay, Sweden.

The indications from right-angled abutment at both right and left sides of Laholms bay (Swe., 8, 13) are that the bar is built mainly from the bottom with but little transportation along the sides of the bay. The stream deflections from either side of the bay toward a probable oldland island now included in the bar indicate currents toward the centre. This is in marked contrast to the last example, taken from the same coast.

Nearly as typical an example is in Dingle bay (Ireland, 172) where the bottom action is dominant, though there is indication of some transportation from the right side of the bay.

There are many cases of bay filling of this type along the Irish coast (Ireland, 7, 9, 15, 51, 62, etc.).

Dundrum and Dundalk bays on the west shore of the Irish sea (Ireland, 61, 70, 71, 81, 82).

Drakes bay, California (Fig. 21), is a broad open bay, with a bay-bar growing near its head. Delta filling is now progressing between the nip and the bar.

Another typical example of the head of a broad bay being aggraded by sea and streams working together is seen in the gulf of Taranto, Italy. From the swinging outline of the shore the sea action is seen to be stronger than the river action, the deltas are either rounded or stunted. The dominant direction of current is seen by the offsets to be from the left (Ital., 212, 201, 202).

At the southwest corner of this gulf where the Crati river enters, the shore is also aggrading. Here the several streams form a great confluent delta, whose form is modified by the sea (Ital., 221, 222, 229, 230).

In Wachusett cove, Alaska, the curve of the shore at the head of the bay was nearly satisfactory to the sea forces, acting therefore sea and river fill at the same point. The great rise and fall of the tides, 18 feet, doubtless prevents the formation of a bar across the mouth of the cove from Bluff point (C. S., 734).

Nateekin bay, Alaska (C. S., 821).

In the upper portion of the valley of San Francisquito bay, Lower California (H. O., 638).

Harbor of Acapulco, Lower California (H. O., 872).

San Juan del Sur, Nicaragua (H. O., 934).

Manzanilla and Santiago bays, Mexico (H. O., 915).

Filling is shown on west coast of Central America (H. O., 1016, details in 1025–1033).

Todos Santos bay, Lower California (H. O., 1046).

Several bays on the east coast of Scotland are of this type, Lunan, Montrose, Aberdeen, Cruden (Scot., 57, 77, 87). The beaches abut sharply against headlands of irregular shorelines, an indication of bottom building.

Sinclairs and Dunnet bays (Scot., 116) similarly indicate growth from the bottom.

Several beaches on Tiree island (Scot., 42) are of this type.

Magilligan Foreland, Figure 22. — Magilligan point (Ireland, 6, 12) is a bay-bar which combines some of the characteristics of tidal cusps with the normal bay-bar features. From the cliff on the left of the bay a gently curving beach extends to the end of the point, indicating growth by alongshore transportation from the left. McKinneys bank points up

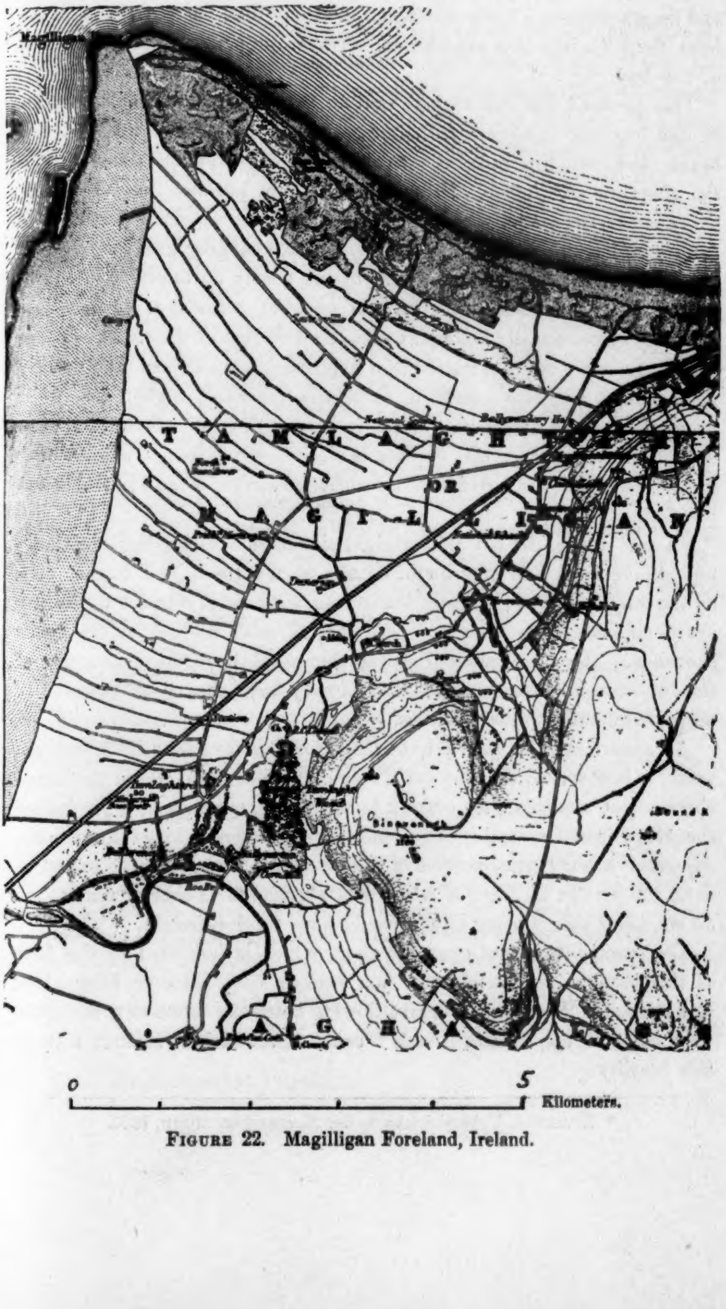

FIGURE 22. Magilligan Foreland, Ireland.

lough Foyle from near the tip of Magilligan point, and its straightness and length suggest a fairly constant and strong tidal current through the inlet, three fourths of a mile broad, between the point and the right side of the bay.

This foreland has the cuspate outline appropriate to a tidal cusp, but on the bay side it shows no line of growth. Back of the present ocean beach, however, are seventeen roads which curve sympathetically with the shoreline of to-day. These roads are not parallel lines, but each curve is nearly parallel with the two on either side, departing just enough from parallelism to make a systematic series, changing gradually from a direction a few points south of west to one nearly northwest and southeast. Between almost every pair of adjacent roads is a ditch, whose course is systematically accordant with the direction of the roads. These culture lines are not constructed in a haphazard manner, and their orderly arrangement suggests a series of successive curves of higher and lower ground. Such a systematic series indicates lines of growth. If this indication be true, then this cuspate bay-bar began some five miles farther up the bay, and has advanced by some seventeen steps to its present position.

As said above, the bay side or right side of the cuspate bay-bar shows no aggradational line of growth. Each of the roads and ditches ends at the high tide line, forming transverse features in respect to the bay shoreline, while the same are longitudinal with respect to the ocean shoreline. This abrupt ending, together with the continuous curve of the bay shoreline, suggests that the sea may have shaved off the ends of these presumable former beaches.

As confirming the above hypothesis for the formation of Magilligan point, it is observed that the cliffs, some 200 feet high, where the alongshore action changes from cutting to aggrading, continue as a nip behind the Magilligan foreland. This cliff is progressively lower toward the supposed earlier formed portion of the foreland. This would be expected, since the portion of the cliff which was exposed for a shorter time to sea action, other things being equal, would have the less height.

The dominant current from the right, which is indicated by the form of this bay-bar, is possibly due to a backset eddy between Islay island and Ireland. The ocean current flowing from the southwest along the west coast of the British islands * could cause such a backset eddy in this locality.

* Krümmel, Uebersichtskarte der Meeresströmungen, 1886.

11. Winged Beheadland.

A Combination of Bay-bar and Cliff. — One of the striking features of adolescent shore development is the winged beheadland. Where the projecting headland has been cut back and transportation has taken place in both directions, spits extend to the right and left from the headland. The winged beheadland is made up of a cliffed headland and two bay-bars, one extending to the right and the other to the left; and this combination of wing-bars with a headland beheaded is so striking a form, and one so characteristic of depressed regions developed to adolescence, that these forms have been grouped separately.

Type: Long Branch, N. J. — From Sandy point to Barnegat inlet is one of the finest winged beheadlands to show the method of formation. The records since the Europeans came to America show the cutting back of the cliffs on the headland, and the shifting of the wings on either side. From the slope of the land above the cliffs upon the headland, it is seen that the land probably projected several miles beyond the present cliffs. The consumption of this land supplied more waste than the sea could immediately carry offshore, and it was temporarily deposited, forming Sandy hook and Island beach. The left wing was probably built in large part from the bottom, and represents the offshore bar of the low New Jersey shore. The cliffs upon Navesink highlands represent the nip, cut before the barrier of Sandy hook was formed.

Other Examples. — Cape Cod is an example of a winged beheadland which projects far into the sea, so that the wings do not extend across bays on either side. The series of changes of the right or Provincetown wing, as indicated by the form, has been worked out by Professor Davis.*

Another typical example is seen on the island of Laaland (Denm., Nakskov, Maribo, Dannemare).

Sejrslev headland (Denm., Lögstör) shows the same form.

Sylt island off the west coast of Schleswig has a right and left wing extending respectively toward Amrum and Röm islands (Germ., 11, 20, 21, 35, 36). The Miocene headland (Geol. Eu., 24) is separated from the rest of the oldland by the drowning, and is therefore somewhat different from the type example.

Insel Poel and Halbinsel Wustrow north of Wismar have both developed wings (Germ., 85, 116). These wing-bars have been curved strongly back toward the mainland.

Similar wings from islands are seen farther north (Germ., 41, 63).

Usedom island is made up of two main headlands with wings (Germ., 89, 90, 121, 122).

Wollin island (Germ., 91, 121, 122).

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* Proc. Amer. Acad., 1896, p. 303.

Samland with its wings protecting Kurische and Frische bays (Germ., 3, 8, 15, 16, 28, 29, 48, 49, 71, 72).

The Pomeranian headland has its right wing enclosing several lagoons, while its left wing is growing into Danziger bay (Germ., 25, 26, 27, 44, 45, 46, 47).

West of the Crimean peninsula there is a very striking winged beheadland (Rus., 33). The initial shoreline is very evidently changed by the cutting back of a projecting headland and the extension of wing-bars, behind which the less altered shoreline is seen. Although the map is not of the highest quality, the scale is small, and the geology of the region is unknown to the writer, he has no hesitation in classifying this feature on account of its typical winged outline.

North of the left-hand wing of the last example is a somewhat similar area, whose origin is, however, not so clear. The outline is similar to a winged beheadland, but the headland is full of small lakes, and it seems probable that it is a part of the Dnieper delta drowned by a late episode of depression. A submergence is indicated by the drowned rivers to the northwest (Rus., 33; Stelier, 48).

12. Tidal Cuspate Forelands.

Location and Description. — In regions of drowned valleys, long inlets, or narrow sounds, where the two opposite shorelines are roughly parallel to each other, cuspate deposits of sand frequently occur, when shore development has reached an adolescent stage and transportation along-shore has begun.

These forelands project from one quarter to three quarters of a mile into the sea, and vary in breadth between the same limits. In some cases the cusps are long and narrow, while in others they are short and broad. Frequently they more or less completely enclose lagoons, but in some instances there is no included water body, or if there was one it has become filled. The curve of the two outer edges of these sand deposits is concave toward the water, and is a continuation of the curve at the base of a shore cliff. These two concave curves intersect in a marked cusp, which is sometimes typically pointed, though in other cases the tip is rounded. The axis of these forelands projects approximately at right angles to the shoreline, and also at right angles to the general direction of the tidal currents in the inlets.

Type, Figure 23. — West point, north of Seattle, Washington, will be taken as the type, and, after giving its description and discussing the method of its formation, others differing in details of form will be considered. Magnolia bluff, two miles northwest of the city of Seattle, has a gently swinging curve, doubtless quite satisfactory to the current here prevailing. This curve continued forms the right boundary of the West point cusp. The curve on the west side of the foreland is in like manner a continuation of the curve of another cliff (C. S., 658; G. S., Seattle).

On the inside of the cusp there is a faint cliff where the coast was nipped after the initial drowning. The central lagoon is nearly all converted

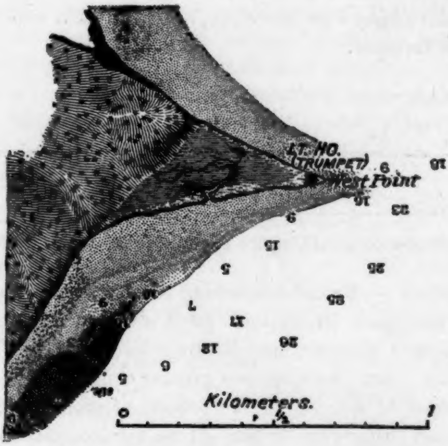

FIGURE 23. Filled Stage of Tidal Cuspate Foreland: West Point, Washington.

into marsh, a small tidal inlet remaining on the left side with a few small ramifying branches. The cusp is very perfectly formed by the intersection of the two curves in a sharp point.

Sand point in Narragansett bay is nearly as typical in form and position as West point. This point projects from the eastern side of Prudence island (C. S., 353) into a channel less than two miles broad and from 10 to 17 fathoms deep, 5½ fathoms off the point of the foreland. This cusp is smaller than the average tidal cusp, and it shows no included lagoon or marsh. Mr. J. B. Woodworth says that the ice in winter overrides this cusp, and thus any indications of embryonic form would be obliterated. The secondary cusp on the left side of the foreland appears to be due to the collection of sand about rocks or piles driven into the sand.

A profile has been drawn from another typical cusp, point Wilson (C. S., 6405), north of Port Townsend, Washington. This drawing (Figure 24) shows the relation of the foreland to the older mainland. The broken line indicates the probable initial form of the land following the depression which inaugurated the present cycle of shore development. The "foreland" quality of the cusp is here clearly seen; it is constructed

by transportation and accumulation in front of the nipped oldland. Although plotted from the soundings and contours about point Wilson, this figure will serve as a general profile of all the cusps of this class. Where the initial slopes were less steep, less contrast is seen between the oldland and the foreland.

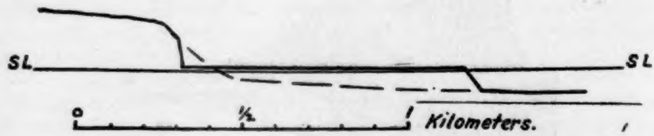

FIGURE 24. Profile of Tidal Cuspate Foreland: Point Wilson, Washington.

Tidal Hypothesis. — Before considering other cusps which differ somewhat from West point, let us look for a moment at what might be expected to result in narrow channels with sides nearly parallel. Waves would attack this inner shoreline to a greater or less extent at all points. When adolescence is reached in the process of shore development, and waste is supplied faster than it can all be carried offshore, it will be transported and deposited somewhere.* The great system of ocean eddy currents is not able to affect this inner as it does the outer shoreline. Local winds must produce small currents proportional to the size of the water bodies, but these will be so weak in narrow channels that their effects will be lost in those of even moderately strong tidal currents. Thus it seems safe to conclude that the probable agent of transportation in such channels is the tidal ebb and flow.

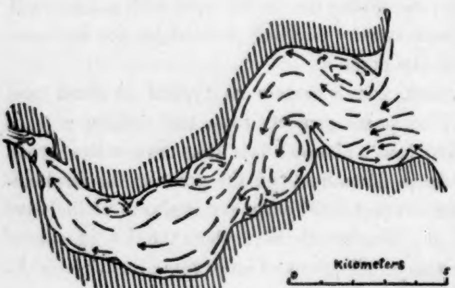

FIGURE 25. — Ideal Scheme of Tidal Inflow: Port Discovery, Washington.

An ideal scheme of inflowing tide, with the eddies which would probably accompany it, is given in Figure 25. Where the movement is least in the triangles of comparatively dead water between the several

* Compare pages 176–178.

members of the circulatory system, the deposition would take place. In the majority of places the outflowing tide would reverse the direction of flow and transportation of shore waste, therefore the combined action of ebb and flow would shape the tidal foreland so that its central axis would be at right angles to the general direction of tidal flow.

The cuspate forelands, which are mentioned under the three following heads, are arranged in three stages of progressive development, — the V-bar stage, the lagoon-marsh stage, and the filled stage.

V-bar Stage. — A much younger stage than that of West point is seen on the same sheet at Meadow point. Here the bars surround a relatively large lagoon, which apparently has hardly begun to fill. The form of this bar is what Mr. Gilbert has called V-shaped.*

Various examples on the east coast of Port Discovery (C. S., 648) show V-shaped bars enclosing lagoons. The majority of forelands in this bay have their greater extension alongshore. Beckett point, however, has its length normally at right angles to the shoreline.

At point Monroe, near Port Madison, Washington (C. S., 663), a looped bar encloses a lagoon somewhat similar to those just mentioned. The shore drift is here all from the left, and the curve of the bar is convex seaward. At point Jefferson farther north on the same sheet there is another convex bar enclosing a lagoon where the drift has been from the left, as shown by the continuation of the cliff curve in the bar. These two examples do not give the typical cuspate form.

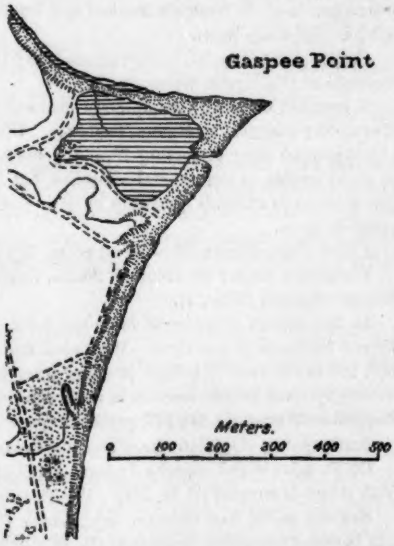

FIGURE 26. Lagoon-marsh Stage of Tidal Cuspate Foreland: Gaspee Point, Narragansett Bay, Rhode Island.

Lagoon-marsh Stage, Figure 26. — Various stages of lagoon filling are shown on the Port Townsend sheet (C. S., 6405, old number, 647). Walan point foreland has considerable area of lagoon, and still maintains open connection with Port Townsend. At point Hudson there remains an unfilled lagoon, but its connection with the sea is lost. At point Wilson a small lagoon now exists, while at Kala point the lagoon

* Lake Bonneville, 57, 58, Pl. VII.

is practically converted into a marsh. On the foreland at Marrowstone point the sand dunes have almost obliterated the marsh.

On this same Port Townsend sheet the rounding of the point of the cusp may be studied. At point Wilson the concave curves intersect in a slightly rounded cusp, while at Kala point the cusp is more blunt, and Walan point is decidedly rounded. The curves at point Hudson have a long radius, so the sides of the cusp are nearly straight, and since they meet at nearly right angles the foreland has a broad flattened appearance. The curve on the right side of Marrowstone point changes from a concave to a convex form, so that it gives that side of this foreland a snubbed look.

Sand point, projecting into Popof strait, Alaska (C. S., 8891), is a fairly typical example of a cusp with enclosed lagoon. The point is here somewhat blunted, more on the southern than the northern side. This foreland as mapped is evidently a piece of made land, built forward in the process of shore development.

A typical example is seen in New Dungeness harbor, Washington (C. S., 646), where inside of the beautiful hooked spit forming the harbor the foreland projects with a very sharp point.

Gaspee point (Fig. 26) in Narragansett bay (C. S., 3047) may be taken as a typical example of this lagoon-marsh stage.

A rounded cusp with completely enclosed lagoon occurs near the mouth of Horup bay (Germ., 24; Denm., Faaborg). Upon the same sheet there is a typically sharp pointed cusp projecting from the north end of Ärö island. This projects at right angles to the general shoreline, but the belt of water is here so wide that the wind-made currents probably have as much controlling influence as the tidal, possibly more.

Filled Stage, Figure 23. — West point, Washington.*

Dungeness point† on Romney marsh, England, is a cuspate projection into the English channel (Eng., 4).

In the eastern entrance to Magellan strait, South America, is one of the largest known forelands of this class. Westward from cape Virgins and south of a nipped cliff 100 to 300 feet in height projects from five to six miles a second Dungeness, named by some British seamen in recognition of a form similar to that of the great English sand cusp (H. O., 443, profile in View A).

Sandy point, Magellan strait, South America (H. O., 450[a]), is another example.

On Douglas island opposite Juneau, Alaska, is a tidal cusp at low water, while at high tide it is covered (C. S., 734). The rise and fall of tide at this point is 18 feet.

Sextant point, San Quentin bay, Lower California, is apparently a cusp built out between two rocky headlands (H. O., 1043).

Estauques point, Venezuela, is a long narrow cusp (H. O., 1087).

Alice point, on the bottom of the foot of the Italian boot, is a foreland which shows no included marsh. Its axis if projected across the gulf of Taranto would touch the extremity of the heel, as if its existence showed the attempt of the sea to close the gulf (Ital., 231).

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* See page 214.

† Topley, Geol. of the Weald, 1875, 211, 303; F. Drew, Romney Marsh, Mem. Geol. Sur. Eng. and Wales, 1864; F. P. Gulliver, Dungeness Foreland, London Geog. Jour., 1897, IX. 536–546.

South of Rettin there is a somewhat irregular cusp (Germ., 84).

A cusp projects into Der Bodden from the southeastern point of Rügen island (Germ., 89).

There are several cusps inside of Frische and Kurische bars (Germ., 3, 8, 15, 16, 29, 48, 49, 71, 72).

In Vejle fjord (Denm., Fredericia), there are several cuspate projections, often called "Hage" or hook, whose form and position indicate eddies in the tidal in and out flow.

At the mouth of the Elbe river, west of Cuxhaven, where fortifications now stand, is a low projecting point, a foreland of this class (Germ., 110).

Two broad, completely filled cuspate forelands occur in the Kieler and Eckernförder bays respectively (Germ., 58). Friedrichsort is built upon the former, while the latter lies six kilometers east of Eckernförder.

Cebú, on an island of the same name among the Philippine islands, is built on a point apparently of this same nature (Spain, Bol. XIII, 1886, Lám V, 1 : 100,000).

A cusp with irregular outline of "Schaaf Land" (Pasture?) is built in front of one of the Holland dikes (Holl., 8).

Landskrona (Swe., 4) is built upon a low cuspate point, which appears to be a foreland of this class. As there are shoals off the point it may be that this is a cusp resulting from the tying on of an island which is now cut away.

Between Helsingborg and Råå there is a rounded foreland, an embryonic tidal cusp (Swe., 4).

A cusp near the head of Skelder bay (Swe., 8) curves around from the usual position at right angles to the tidal currents and points toward the mouth of the bay. The presence of oldland may account for this, but the form of the cusp indicates a change in direction of growth from the normal position at right angles to the shoreline to one where a spit is growing from the cuspate point toward the right.

Methods of Growth. — It would seem from inspection of the maps that it was the more common thing to enclose lagoons, though in some places the growth has evidently begun at the mainland and progressed outwards. In False Dungeness harbor some of these cuspate deposits are seen which do not appear to have ever enclosed any lagoons (C. S., 646). Three of the cusps on the inside of the Coatue Spit, Nantucket, have no lagoons, but as the other two have, and since they are nearer the end of the spit and hence probably later formed, it is quite likely that the earlier formed forelands also began with lagoons (C. S., 111, 343; G. S., Nantucket, Mass.).

Professor Shaler has ascribed these Coatue cusps to tidal whirlpools. He says: "From a superficial inspection it appears that the tidal waters are thrown into a series of whirlpools, which excavate the shores between these salients and accumulate the sand on the spits." *

* Bull. U. S. G. S., No. 53, 1889, 13.

Among these filled cusps are included doubtless those which have passed through the V-bar stage as well as those which have grown by gradual out-building, since from present knowledge it is impossible to separate the two groups. With better maps and descriptions of the cusps a later classification will make closer distinctions.

Theory confronted with Fact. — After this general survey of the varying forms of cuspate forelands selected from the many examples in the narrow water bodies of the world, the following generalization may be made. However varied the form resulting from the local conditions, tides, relief of oldland, etc., the axis, or a line drawn from the point of the cusp through the centre of the foreland, is always at right angles to the general direction of flow of the tidal currents.

Where there are strong tides, as in Puget sound, Chesapeake bay, and Narragansett bay, there are numerous and typical cuspate forelands; while in Albemarle sound the range of tides is less than one foot, and here few sandy points of a cuspate form occur.

Thus the facts of observation seem to correspond with the principal requirement of the theory. Studies of the existing currents in regions where these forelands are found are now needed to further test the tidal hypothesis. From present knowledge this seems to be the best working hypothesis.

Two methods of growth are suggested. In one the outline of the foreland is early given by a V-bar, and later this enclosed lagoon is progressively filled. In the other the foreland grows by successive additions to the mainland. The first appears to be by far the larger class; though the examples of the latter are liable to be confused with the filled stage of the first class.

Between the narrow channels and the open sea there are all gradations in size of water bodies, so we should expect to find forelands built by combination of tidal and wind currents in different proportions. Such cases have been referred to in Del Faro point, Ärö island cusp, and Alice point.

13. Bay-deltas.

History of a Drowned Valley. — Bay-deltas fill drowned valleys. The term *ria,* from the Spanish, may be advantageously used to cover all types of subaerially carved troughs, including von Richthofen's fjord, ria, dalmation, and liman types.* After depression, the stream in youth

* Führer, 305-312. Compare use by Penck, Morphologie der Erdoberfläche, II. 562-582.

builds a delta at the head of the ria or drowned valley, in adolescence it pushes it well forward, and in maturity it has completely driven the sea out of the valley and thus obliterated the initial shoreline of depression. Bay-deltas, or ria-deltas will here be grouped under the three heads, young, adolescent, and mature.

Type Young Bay-delta: Loch Fine, Figure 27. — The type is seen in loch Fine (Scot., 37) where Fine river has begun to fill the drowned valley. Shira river farther west has also begun to fill, and later the two streams will join their deltas, filling up the lower portion of the ria. At the head of this long bay the delta form is practically free from complication due to sea action, which in so many cases influences the form of filling.

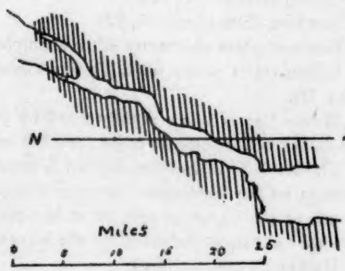

FIGURE 27. Young Bay-delta: Loch Fine, Scotland.

Other Young Bay-deltas. — Many occur on the northwestern coast of Spain, from which locality the generic term "ria" was taken (Stieler, 33; Spain, Bol. VII, 1880, Lám. D).

Strath Beag at the head of loch Eireboll (Scot., 114).

Loin water at the head of loch Long (Scot., 38).

At the heads of loch Lomond (Scot., 38, 46); loch Awe (Scot., 45); loch Striven (Scot., 29); loch Etive (Scot., 45); loch Maree (Scot., 92); loch Broom (Scot., 92); loch Duich (Scot., 72); etc.

Tomales bay,* California, a well marked "ria," shows delta filling at its head (C. S., 631).

Drago delta, Austria (Austr., 25, IX). This stream is small, and has not yet filled much of the ria, Canale di Leme.

Type Adolescent Bay-delta: Dwamish. — The Dwamish river pushing forward its delta to fill Elliott bay is the type. Seattle, built upon the mainland along the margin of both the delta and the unfilled bay, has a splendid combination of elevated locations for residences, flat delta land for future business blocks, and a water front on deep tide water. As the delta grows forward the city will occupy it, probably accelerating its advance, and transfer the shipping interests farther down the bay (C. S., 651; G. S. Seattle).

* See page 196.

Other Examples. — The larger streams in the Puget sound region, notably the Skokomish, de Chate, Nisqually, Puyallup, and Snohomish (C. S., 6450, 6460, 690, 644).

The Tay river has filled about half of the valley which the firth occupied after the depression (Scot., 48).

Kyle of Durness and kyle of Tongur (Scot., 114).

Ruel strath (Scot., 29, 37).

Sachaig strath (Scot., 37).

Clyde delta (Scot., 38).

Carron delta (Scot., 92).

Torridon delta (Scot., 91, 92).

Scotland gives also many other examples.

Bilbao ria is partly filled (Spain, Vizcaya, 1892, Lám. 1; Spain, Bol. III, 1865, Lám. D).

Mobile bay is being rapidly filled by waste from the Alabama rivers, although the delta front is some 30 miles from the mouth of the bay (C. S., 188).

The ria-delta in Irondequoit bay is not so far advanced as the Dwamish, and is perhaps on the border line between the periods of youth and adolescence. The mouth of the bay is closed by a bay-bar, so the stream will be able to push forward its delta undisturbed by the waves of lake Ontario.

Halkjaer (Denm., Nibe).

Randers (Denm., Mariager).

Vejle is built on the delta growing forward into Vejle fjord (Denm., Fredericia).

The stream emptying into Rands fjord (Denm., Fredericia).

Several streams entering into Odense fjord (Denm., Hindsholm, Nyborg).

Quieto and Dragogna rivers, Austria (Austr., 24, IX).

Arsa delta, Austria (Austr., 25, X).

Bado delta, Austria (Austr., 26, X).

In St. Jördals fjord (Nor., 47, C).

Ler river (Nor., 15, C).

The Dniester (Rus., 33).

The Gedis delta in Asia Minor (Brit. Ad., 1523, Map II, Dr. C. Cold, Küstenveränderungen im Archipel, München, 1886) has grown, even in historical times, into the gulf of Smyrna, and will soon geographically cut in two the harbor of Smyrna and leave that city without communication with the Ægean sea.

The above mentioned catastrophe has happened to Heraclea and other places south of Smyrna on the coast of Asia Minor, where the Mæander has nearly filled its ria (Brit. Ad., 1555; Cold, loc. cit., Map III).

Type Mature Bay-delta: Simeto, Figure 28. — South of the volcanic mass of Etna, the three rivers Simeto, Dittaino, and Gorna Lunga have built a common flood plain and delta of recent alluvium. This is a beautifully mapped illustration of the ideal form of a delta-filled bay (Ital. and Sicily, 269, 270, 273, 274). The filling may have been contemporaneous with a slow sinking of the region, or the space now occupied by the flood plain may be simply what was not filled with the lava. The form is so typical however that it is given as the best mapped

example of a mature bay-delta, although there is some doubt as to the early stages of this example.

Other Examples. — In Chehalis river, Washington, the delta has filled not only the drowned valley, but has also considerably filled North and South bays between the nipped coast and the bar (C. S., 643).

A similar case is Willapa river, Washington (C. S., 681[a], 642, and 6180).

Solkjoer river has completely filled its ria (Denm., Skamlings Banke), except for a small pond. The deflection of the mouth is to the left, indicating a current from the right.

FIGURE 28. Mature Bay-delta: Simeto, Sicily.

Taubaek (Denm., Nibe).

Kastbjerg (Denm., Mariager).

Narenta river has nearly filled the drowned portion of its valley (Austr. 33, XVII).

The Guadalhorce river has filled its ria; also the Vélex (Spain, Bol. XVII, 1991, Lám. A; XVIII, 1892, Lám. A).

Lake Bay-deltas. — Lakes whose basins are portions of river valleys frequently show, at the end where the stream enters, deltas of similar form to those mentioned above. These deltas show almost complete river intention, since ocean currents and tides do not affect them, and the narrow water bodies do not permit the winds to stir up very destructive waves.

The delta of the Ticino river in lake Maggiore, Italy, is a typical example (Pet. Geog. Mitt., Erg. XIV., Nr. 65, 1881, Taf. III.).

See also the delta of the Rhone in lake Geneva (Carta Geologica d' Italia, Roma, 1889); that of the Aare in lake Neuchâtel (Swiss, VIII, and Carta dell' Italia Superiore, by R. Lenzinger, Zürich); etc.

Bonneville Bay-deltas. — Almost all the streams entered lake Bonneville through mountain gorges, and the detritus of the Bonneville epoch was deposited in these narrow estuaries forming bay-deltas, the water at the Bonneville level having entered the previously eroded valleys. When the water fell the detritus was carried away, leaving no deposit to mark the Bonneville shoreline in these larger streams.*

14. Deltas.

Ratio between Sea and River Activities. — The shore changes caused by delta growth depend on the ratio between sea and river activity more than upon any other factor; and deltas would therefore be typically developed either after uplift or depression. The area of a delta is a measure of time since the beginning of a cycle. A large river will soon build a great delta, a precocious infant; but the delta will attain its maximum area at some period in late adolescence or maturity, after which the delta will diminish in area by the degrading of the river. A smaller stream has a similar maximum area, though its dimensions at any given stage are always less.

The life of a river is in a sense to be considered apart from the cycles of coastal plain development and also as distinct from the other shore changes, though its life is intimately connected with and a most important part of both sets of processes. The river's aim is to convey the load given it by the land to the sea. Of itself it would build forward a lobe for each distributary, the shifting of these distributaries on account of the upbuilding causing in time a broad fan-shaped deposit, so well shown in the confluent delta of the Hoang and Yangtze rivers.

The sea, on the other hand, desires a straight shoreline. The delta intention is opposed to its attack upon the land, and therefore the sea aims to cut off the front of the lobes and carry the delta waste out to sea, depositing it beyond wave attack or below wave-base.

The form of a delta front does not indicate sharply the stage of the cycle in which a given region stands. The relative strength of sea and river may cause a given form of delta front at many stages in the life history of a region. The river activity is increasing from birth toward maturity, so that in the case of any given river there will come a time of maximum activity, when the river will be best able to push forward and build a lobate delta into the sea. This time, however, may not be the time when there is the greatest likelihood of the formation of such a

* Gilbert, Lake Bonneville, 154.

lobate delta, for the activity of the sea is also a variable, and it may happen that the ratio between the two activities is more strongly in favor of the river at some time before or at some time after its period of maximum activity. For example, if the time of maximum activity of the sea on a given shore occurs at a later stage than the time of the maximum activity of a certain river, the largest ratio in favor of the river will probably occur considerably before its maximum; while if the sea's maximum occurs at an earlier stage of shore development, and is decreasing at a more rapid rate than the river's activity, the ratio in favor of the river will be greater after its maximum is passed.

It may be that the sea action is so strong off any river's mouth that the river never is able to carry out its intention. Indeed, this seems to be the case in a large proportion of the rivers of the world. The sea is relatively stronger than the river in all cases except where the volume of the river is exceptionally great, as in the Mississippi, or where the mouth is protected from the stronger sea attack, as is the case of the Po at the head of the comparatively narrow Adriatic.

Delta Stages. — In the initial stage deltas do not exist. At any time after the beginning of a cycle, a delta may be built, whose size will depend far more on the volume and drainage area of the river than upon the time since uplift.

In the cycle following uplift a delta of a certain frontal outline may occur at various stages, and the forms appropriate to successive stages have not been worked out, because of the many complications of the problem, some of whose factors are indeterminate. Deltas doubtless follow a normal succession of forms under the various conditions. This has been shown to be true in the case of bay-deltas. A delta foreland of any considerable size would not be found projecting from an initial coast, where the valleys of all the larger river systems had been submerged. Until maturity of shore development has been reached, large delta forelands would consequently not be expected upon depressed regions.

Credner. — Dr. Credner's monograph on Deltas* is to-day, nearly twenty years after its publication, the most complete source of information about the deltas of the world. While his descriptive portions are classics, the theoretical conclusions of the text seem open to question. Dr. Credner apparently looked at deltas as phenomena requiring some common cause which would account for their presence or absence. He

* Die Deltas, Pet. Geog. Mitt., Erg. XII., Nr. 56, 1878.

found that deltas were not due necessarily to a large amount of sediment; that they are not explained by the greater or less velocity of current; that their presence is not determined by a deep or shallow sea in front of the mouth of the river; that they are not explained by the presence or absence of an offshore bar; that they occur even where tides are strong; that "the presence of a controlling ocean current (Tiber, Rhone) does not alone suffice to prevent the formation of deltas"; and, finally, that deltas are not prevented by the wind. He then goes on to show that delta growth is aided by slow elevation and hindered or prevented by gradual depression. He concludes that relative elevation of the land with respect to the water is the controlling cause of delta growth.

Such slow elevation of the land is surely an aid to delta extension, but it is only one of the factors which work together in the determination of delta growth; and cannot be considered necessary, in the opinion of the present writer, for the aggradation of a coast line by rivers.

Further Study. — The subject of deltas offers a very attractive field for investigation. The writer has not been able to make out nearly as much as he had expected to in regard to the stages of development shown by deltas. He is convinced that each delta goes through appropriate stages, but the variables are so many, and vary between such wide limits, that the laws of development are not clearly seen. Vigorous advancing deltas are characteristic of maturity, following both uplift and depression. But the maximum of delta growth may be either before or after this period, as shown above. Bay-deltas have been separated from the rest, as they show characteristic stages following depression. When better understood, other deltas will fall into their appropriate stages.

Classification. — Deltas are here classified, not according to stage in cycle, but according to ratio of activity between river and sea. The examples of shore development by delta growth are arranged in the following series.

1. Lobate deltas: (*a*) unilobate; (*b*) multilobate.

These show the river intention successful.

2. Cuspate-lobate deltas.

The river intention is in these deltas predominant, but the sea action prevents typical lobes.

3. Cuspate deltas.

The river mouths at the point of intersection of two shore curves, concave seaward.

4. Rounded deltas.

The shore currents prevent the cuspate extension.

5. Stunted deltas.

The stream in this case is able to alter but slightly the shore curve.

6. Blocked streams.

The sea here builds a bar closing the mouth of the river. This ratio was recognized by Dana,* who used the term *blocked*.

1. *Lobate Deltas.* (*a*) *Unilobate type.* — In this class are those deltas in which a single lobe is formed by a single stream, showing pure river intention. No very typical example has been found.

The delta of the Mæander (Brit. Ad., 1555; Dr. C. Cold, Küsten veränderungen im Archipel, München, 1886, Map III) has now a typical unilobate front, projecting from the nearly straight front of the almost filled ria.

The Ebro is of the general form of the unilobate delta, slightly modified toward a multilobate type (Credner, loc. cit., 17; Spain, Bol. XVI, 1889, Lám. A).

(*b*) *Multilobate Type.* — The type is the Mississippi. This classic example is so well known, and has been so frequently given to illustrate successful river intention, that a description is here unnecessary.

The Kilia or northern distributary of the Danube (Rus., A; Credner, loc. cit., 23).

The Volga (Rus., 114; Credner, loc. cit., 16; Pet. Geog. Mitt., IV., 1858, Tom. V.).

The Atrato (Credner, loc. cit., 5).

The Po (Stieler, 23) shows the river intention dominant, with partial cutting off of the more exposed lobes.

The Gedis delta in the gulf of Smyrna (Brit. Ad., 1523; Cold, loc. cit., Map II; Credner, loc. cit., 11).

The Rhone (Fr., 233, 234, 235, 246, 247) has a form midway between the Mississippi and the Tagliamento.

2. *Cuspate-lobate Deltas.* — The type is the Tagliamento at the head of the Adriatic (Austr., 22, VIII, IX; 23, VIII, IX). The river intention is plainly seen in the form of the delta front, but the alongshore currents prevent the formation of typical lobes. Former positions of the delta front are indicated by the lines of villages on the higher ground. Three of these lines are seen west of Palmanova (Austr., 22, VIII). On the earliest shoreline are situated Gonars, Castions, Flambro, Rivolto, Codroipo, and intermediate places; on a later and less clearly marked line are Castello, Paradiso, Torsa, Ariis, and Rivignano; while a third stage in the growth of the delta is indicated by the road connecting St. Giorgio with Latisana. These lines are more or less perfect divides across which but few streams cut, and these few gather the many small watercourses from the areas which represent the filled lagoons. The transition from lagoon to marsh, to wet meadow, and finally to a rich lowland plain capable of high cultivation, is beautifully shown in going inland from the Adriatic east of the Tagliamento.

The Danube delta (Rus., A) shows many former channels with recent changes. That the river has been pushing forward is also indicated by the marshy, reed-covered surface, but thinly populated.†

Fraser river, British Columbia (H. O., 961).

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* Manual, 3d ed., 1880, 683.

† Draghicénu, Jahrb. k. k. geol. Reichs., 1890, XL. 409.

Holland (Atlas Univ., 26) is in large part a great confluent delta formed largely by the Rhine and adjacent streams.

The Nile is a multi-cuspate-lobate delta (Brit. Ad. 2573, 2630; Credner, loc. cit., 2).

8. *Cuspate Deltas.** — The typical example of a cuspate delta is given in Figure 29. The two gently swinging shore curves, concave seawards, with their dune-lined beaches, are the work of the sea. At the point of intersection of these two curves the river empties. The form of the land shows that, if it were not for the river, there would not be any cusp here, as there is no projecting point in the oldland to cause eddies in the currents. The evidence from the turning of the mouths of the small streams both to right and left indicates that the direction of current motion alongshore is probably sometimes in one direction, and sometimes in the reverse. The smaller streams on each side of the river's mouth are deflected away from the point of the cusp, indicating that the delta mass divided an onshore current and turned it to the right and left, carrying the river sediment from the river along the shore. Farther from the river, both on the right and left sides, there are streams deflected toward the mouth of the main stream. There is here evidently no dominant movement in either direction along the shore.

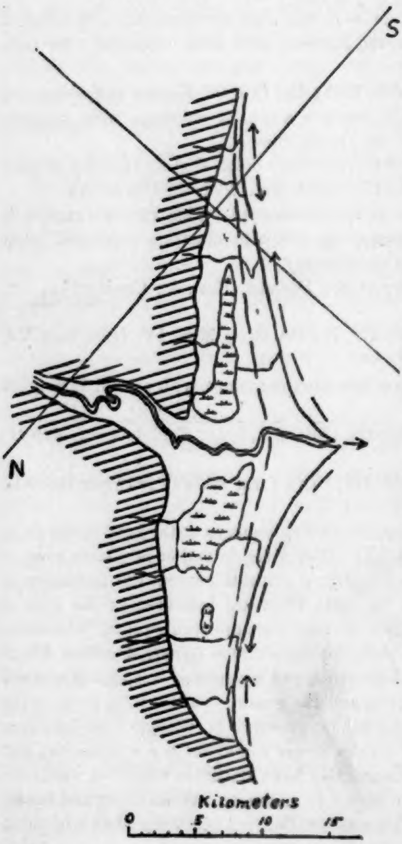

FIGURE 29. Typical Cuspate Delta: Tiber, Italy.

A former stage of the delta is indicated by the ridge of geologically older material, which is represented in the figure by the broken line. This earlier stage of the delta front is seen to have a rounded outline. This suggests that formerly there was a dominant movement alongshore. Back of this former shoreline are seen areas of marsh, filled lagoons, or lowland behind the old beach. Since this leap from some still earlier position of the shoreline, the forward growth seems to have been

* For fuller discussion, see Bull. G. S. A., 1896, VII. 417-421.

gradual, for no long slashes of swamp are shown. This type is the Tiber (Ital., 149; Carta Geologica della Campagna Romana, Roma, 1888).

The Angitola delta (Ital., 241) extends a small cuspate point beyond the curve of the bay-bar, as if the stream crossing the bar was relatively strong enough to divide the alongshore current. It has been found impossible to pick out from the other examples of cuspate deltas given below, any which were later stages of this embryonic type. The maps give little more than the form of the latest stage of development. The forms should be studied on the ground, in order to see what was the embryonic condition. This study is analogous with what is done by the paleontologist when he peels off the outer shell of an Ammonite in order to discover its embryonic form.

In both the Biferno (Ital., 155) and the Ofanto rivers (Ital., 165) the deflections indicate a current from the right at present, though formerly the deflection was in the opposite direction, according to the indications from inland form.

In the two following examples of deltas, Volturno (Ital., 171, 172, 184) and Ombrone (Ital., 127, 128, 135), the streams are deflected in both directions, thus indicating no dominant current alongshore.

The current is probably from the left in front of Alento delta (Ital., 141) and from the right at Neto delta (Ital., 238).

Düna river (Rus., 13) has a cuspate foreland projecting into the Gulf of Riga. The deflection of the Aa river to the left indicates a strong current from the right at the head of this gulf.

The Aa de Livonie, east of the Düna, also has a cuspate outline (Rus., 13).

Punta Arenas, a Chilean settlement, South America, is built on a foreland made by combined action of river and sea (H. O., 450[a]). Deflection is to the left.

A variation from the typical form is seen in the hooked point of Ausable delta in Lake Champlain (C. S., 554; G. S., Plattsburg, N. Y.).

In the Volstrap at Aaeby (Denm., Frederikshavn) the southward deflection of the mouth indicates a prevailing current from the right.

The Danzig mouth of the Vistula (Germ., 70) shows deflection to the right.

Kolberg is built on the cuspate delta of the Persante (Germ., 93). The evidence along this coast is for a current from the right.

Many of the discharge sluices emptying into the Zuyder Zee have built cuspate deltas, and though aided by artificial means, the form is so typically cuspate that they are included in this category (Holl., 15, 16, 21, 26, 27, 32).

4. *Rounded Deltas.* — The type of this class of deltas is that of the Arno (Ital., 104, 111). The delta front is bounded by a curve convex seaward, changing into the shore curves concave seaward. In contrast with the case of the Tiber the river is here not strong enough to separate the alongshore current into two eddies. The current swings around the delta, and gives it a smoothed outline in place of a cuspate.

Fortore delta, Italy (Ital., 155). This sheet shows a portion of the former channel, *fiúme morto,* on the left wing of the delta.

The Sinni, Agri, and Basento deltas (Ital., 212, 201). Dominant current from left.

The Sele delta, Italy (Ital., 197, 198). Dominant current from right.

Sangro and Trigno deltas, Italy (Ital., 148). Currents uncertain.

Vomano, Saline, and Pescara deltas, Italy (Ital., 141). Dominant current from right.

Savuto delta, Italy (Ital., 236).

Crati delta, Italy (Ital., 222). Current from left.

Trionto delta, Italy (Ital., 230). Currents in both directions.

The Fiumenica delta, Italy (Ital., 231). Mouth deflected to right.

The Esk delta upon which Musselburgh is built (Scot., 32) shows no dominant current.

The deflection of over 2,000 meters of the ditch-like stream near Lyngsaa suggests current from right (Denm., Frederikshavn).

The northward deflection of the mouth of the Liver river with its rounded delta, indicates a current from the right (Denm., Hirshals).

Marathon delta, Greece (Attica, XVIII). Current from the left.

Rega (Germ., 92); Wipper (Germ., 66); and Stolpe (Germ., 44). All three indicate a slightly dominant current from right.

Rion delta, at the eastern end of the Black sea (Rus., 80; Stieler, 49). Streams are deflected to the right and to the left from the mouth of the river.

The Rio Grande (C. S, 212) has filled a considerable portion of the lagoon, enclosed farther north by Padre island or the great Texan offshore bar, and is now advancing in front of the bar at Bagdad, having in recent geographic time abandoned the distributary running toward Boca Chica inlet.

The Llobregat (Spain, Barcelona).

5. *Stunted Deltas.* — In a fifth class of deltas the relative strength of the stream is so much less than that of the sea that the shoreline curves around the front, making almost no change in its curvature at the mouth of the river.

An example is seen in Figure 30, where the Cavone empties into the Adriatic (Ital., 212), making a very slight convexity. The dominant current in the gulf of Taranto is from the left.

The Soltane makes but faint projection into the gulf of Tunis (Tunis, XXI). Easterly current.

The Simeto delta, Sicily (Ital. and Sicily, 270, 274). The deflection of the mouth is toward the right. The bottom cutting of the sea is judged to be greater than its alongshore action, because the beach abuts nearly at right angles against the lava at Catania and Agnone (Fig. 28).

The Simeri river is cut off without any delta growth (Ital., 242). Deflection is about equal in both directions.

Acate delta, Sicily (Ital. and Sicily, 272, 275). Dominant current from the right.

The delta of Garigliano river, Italy, makes but a faint projection against the sea (Ital., 171). Deflection to right.

Lama d'Arco delta (Ital., 201) and Lato and Lenna deltas (Ital., 202) on the gulf of Taranto, Italy. Dominant current is from the left.

F. Alento, Italy, is not allowed by the sea to build forward its delta (Ital., 209). Current from left, as deflection is to right.

F. Oliva, Italy (Ital., 236).

Several streams on the Catanzaro sheet (Ital., 242). Currents about equally from right and left.

The ditch-like stream 4,000 meters north of Saeby enters the sea with no deflection and producing no apparent alteration in the shore curve; a similar stream six kilometers south of Saeby causes as little alteration in the shore curve, but it is deflected 800 meters to the south, which indicates a current from the right; a third

variety of stunted delta shown on the same sheet is that of another ditch-like stream, one kilometer north of Vorsaa, which produces slight alteration in the shore curve and is not deflected, but the land on the north of the stream decidedly offsets that upon the south, indicating again a current from the right (Denm., Frederikshavn).

Kolkjaer and Brendelsig give no indication as to direction of current (Denm., Aalborg).

Haslevgd is deflected to the south, suggesting a current from right (Denm., Mariager).

Kjul, Ugerby, and Tversted deltas suggest current from right (Denm., Hirshals).

Guadalaviar ó Turia (Spain, Valencia).

FIGURE 30. Typical Stunted Delta: Cavone, Italy.

The Tinto river is strongly deflected to the right and shows very little projection of a delta (Spain, Huelva; Stieler, 35).

The Tet delta (Fr., 255).

6. *Blocked Streams.* — If the sea action is relatively stronger than in the last case it may close up completely the mouth of the rivers (Fig. 31). The water from the typical ponded streams on the Oceanside sheet, California, reaches the sea by percolation through the beach.

The stream intention is often completely blocked by the sea when the water is carried in a deflected course far to the right or left, and such examples have been included in this category.

An example of a blocked stream of a different type from the Oceanside case is seen in the Vistula (Germ., 70, 71, 99, 100). The sea here blocks the course of the river and carries out its intention of a concave shoreline. The main work of the river at present seems to be filling up Frische lagoon into which the main distributaries have been turned, since the aggradation of the drowned valley.

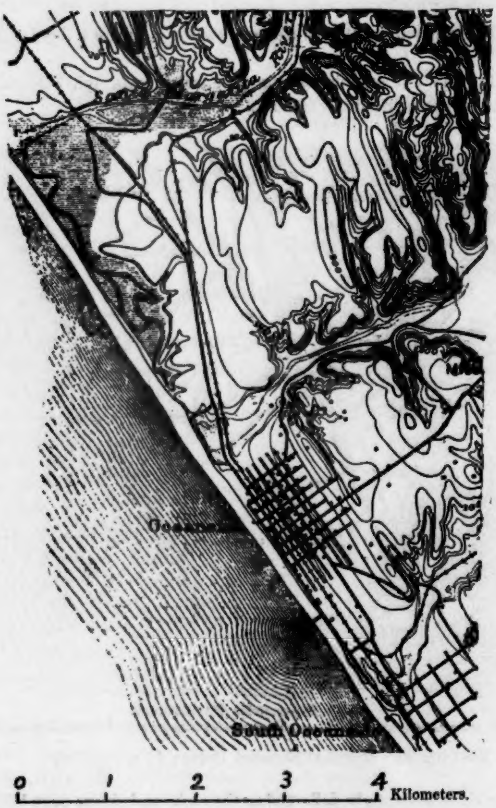

FIGURE 31. Blocked Stream: Oceanside, California.

The delta of El Rincon river on the north side of the ridge south of which the stream flows is an anomalous feature, until one perceives that in the contest between river intention and sea intention the latter has been victorious. A current from the left flowing up the gulf of Dulce is indicated, such current having forced the stream to turn a right angle around the point (H. O., 1036).

Sea intention versus river intention is prettily shown at Coos bay, Oregon (C.

S., 5984). The spit formed by the southward flowing current has crowded the river as far south as possible, close to the cliffs on Coos head.

Another good example of a river forced against a rocky headland by the sea is seen in Garcia river at point Arena (C. S., 661).

Bezirk river is lost in the sand dunes before reaching the gulf of Tunis (Tunis, XXI). Current is indicated from the left.

15. Tidal Scour.

Action in Bays. — Tides as abrading agents are most effective in drowned valleys. The destructive effects of the bore have been much discussed, and more work has been ascribed to this inrush of tidal waters than that for which it is probably responsible. The depth to which tides may scour a submarine channel is still a very problematical question, and the amount of wearing of the shores by the tides is a subject needing study.*

Tides are not here taken up at any length, because the relation of their products to stage of cycle is not as yet shown. The forms of shores as determined by the changing ratios between tidal on- and offshore and alongshore currents is the only point upon which emphasis is here laid. As in the consideration of deltas, this point is dwelt upon because it shows so clearly the importance of perceiving the varying ratios between the several factors that determine shore forms.

Runways. — On flat coasts where there are broad surfaces covered at high and bare at low tide or wide stretches of tidal marsh, there is opportunity for much tidal work. When the main body of ocean water retreats during ebb tide, that portion lying upon the flats must flow off down the easiest path, and thus runways are formed dissecting the surface. Such runways may be broad or narrow, deep or shallow, short or long, etc., according to the values of the varying factors which obtain in any given case. The scouring action may continue below low tide level, to greater depths, the greater the range of tide and volume of water passing through the runways.

The tidal scour if strong would tend to prevent the tying of islands and closing of bays, which are normal features of shorelines in an adolescent stage of development.

Such prevention of island-tying is seen on the Schleswig coast, where from the stage of development indicated by the long wings on Sylt island (page 213), the development of tombolos would be expected. It

* For the discussion of the scouring of tides in estuaries, see papers by the following authors: Bache, Branner, Dana, Ferrel, Mitchell, Shelford, and Sollas.

seems therefore justifiable to infer that in this locality strong tidal runs have prevented the growth of tombolos.

The form of the tidal runway is of the indefinite type of channels, called *insequent* by Professor Davis. A broad tidal flat will be cut by runways forming a dendritic drainage pattern (Germ., 5, 36, 37, 79, 80). Where there are large rivers, the pattern of dissection will show the controlling influence of the master stream (Germ., 109, 110, 111).

Ratio between Tides and Currents. — The relative strength of tidal on- and offshore action and alongshore current action is a most important consideration in the determination of the form of coasts. The form of the North Carolina coast indicates that back-set eddies * are relatively stronger than the tides. The prevailing extension of water bodies is along the shore. These alongshore channels or lagoons are connected with the ocean by tidal inlets which cross the bars, and whose position is constantly shifted by alongshore transportation. These inlets represent the weaker tidal intention working at right angles to the general shoreline, while the lagoons indicate the stronger alongshore action.

Something of the insequent pattern is seen in the ramifying channels inside the offshore bar at Bogue and New River inlets, North Carolina (C. S., 148). Southward along the Carolina coast the alongshore action would appear from the shore forms to diminish in strength in relation to the tidal in- and outflow.

Series of Forms. — It is possible to arrange shores in a progressive series according to the ratio between tidal on- and offshore and alongshore currents. This series is not one following stages of development, but one which is determined by the ratio between two variables, whose average directions of activity are at right angles to each other.

The normal development of shorelines as affected by the sea should however be kept in mind, and allowance made in each example for the stage of development indicated.

When the ratio is in favor of the alongshore current, the forms developed should show extension in the general direction of the shoreline; when on the other hand the ratio is in favor of the tides, the most pronounced shore feature should be development at right angles to the shoreline.

Western Florida Type. — On the western shores of Florida, although the tides are weak, the ratio between tide and current action is inferred to be preponderantly in favor of the tidal, as indicated by the form of

* See page 180, and Bull. G. S. A., 1896, VII. 405.

the shore (C. S., 180, 181). These two sheets show almost no indication of alongshore work. The shoreline is minutely irregular from the dissections of the tidal runways. The bottom is very shallow, the three-fathom line extending on an average eight miles from the shoreline. The average rise of the tide is here 2.5 feet.

The runways off this coast are not so deep nor so markedly dendritic as in the succeeding case, but the stream pattern is very irregular.

Schleswig-Holstein Type. — On the west coast of the Schleswig-Holstein peninsula (Germ., 5, 11, 20, 21, 35, 36, 37, 55, 56, 79, 80, 109, 110, 111) occurs an example of marked tidal scour. The west coast of the Schleswig-Holstein peninsula from the mouth of the Elbe to the Danish boundary is low and flat, with many outlying islands of the same character. The spaces between islands and mainland are occupied by broad flats, bare at low tide, with steep-sided channels dissecting them. Some of these channels are continuations of existing valleys on the mainland, and were possibly cut when the land stood higher. Others however head upon the flats, and appear to be runways cut by the tide. The volume of water covering the broad flats at high tide must have considerable scouring power when confined in these narrow channels, and it has probably cut many new channels and deepened previously existing inequalities.

Offsets, overlaps, and stream deflections indicate a dominant current from the right in this region, whose existence is proved by observation.* Generalizations need to be followed by detailed study and observation of localities. Wherever possible to include facts of local observation, it has here been done, but of many localities there are no descriptions. In the present case it is possible to compare the rate of alongshore current and the range of tides.

The resultant for the year 1880–81 of the northward flowing current along the west coast of Jutland was eighteen nautical miles in twenty-four hours or 0.75 mile per hour.† The rate of flow is probably not so great along the less exposed coast immediately north of the Elbe river. The range of the tides off this west coast of the Schleswig-Holstein peninsula is from 2.75 meters to 3.50 meters (Germ., 20).

The volume of water which flows off these flats must be large on account of the breadth of the area flooded at high tide. The form plainly indicates that with the above ratio between alongshore currents

* H. Mohn, The North Ocean, p. 166, Pl. XLIII.

† *Loc. cit.*, p. 168.

and the tides, and the volume of tidal waters, the tidal in and out flow largely determines the forms developed.

The stage of development of this shoreline is one which shows characteristic features of adolescence. The projecting headland of Sylt island is graded and has characteristic wings on right and left. The sea is now carrying this shoreline landward. The islands of Fano, Röm, and Amrum were at an earlier period graded, as is indicated by their form, and are now locally aggrading, as is indicated by the outlying sand banks built in front of probable former shorelines. This geographic interpretation is found to accord with the geology as given by Dr. L. Meyn.*

The relation of such marked tidal scour to the adolescent stage of development of this coast is not clear. The sequence of tidal forms during successive stages of cycles is a subject needing much further study.

Georgia-South Carolina Type. — In the case of portions of the Georgia-South Carolina coast (C. S., 152, 153, 154, 155, 156) the ratio is less in favor of the tides, although they are still the controlling factor in the development of coastal forms. The shore curves are not continuous for long distances, nor are the offsets arranged systematically. Many tidal channels interrupt the sea beaches. These tidal runways are prevailingly at right angles to the general direction of the shoreline, but there are many connecting channels which run alongshore roughly parallel to the beaches.

With the exception of Bulls bay (C. S., 153), where there are broad flats covered at high and bare at low tide, the runways drain great areas of salt marsh. The detritus brought down by streams from the land, the sands blown by the wind, and the growth of swamp vegetation, as well as the action of salt water upon mud-laden waters, all tend to convert flats into solid land.† The tidal scour is opposed to this filling, and carries off what it can by its runways into deeper water, to be finally built into the continental delta.

The control of tidal runways by large rivers is shown in this region by the Savannah, Broad, and Winyah. Tidal channels are turned toward the stream current in some places, while in others the river fills up the runways with detritus causing the water to flow away from the river, in

* Geologische-Uebersichtskarte der Provinz Schleswig-Holstein, 1 : 300,000, Berlin, 1881.

† See discussion by Prof. Shaler, 6th Ann. Rep. U. S. G. S., 1884-85, 360, 361; and 10th Ann. Rep. U. S. G. S., 1888-89, 261-264.

the same manner that a river higher up in its course causes streams to flow away from the main channel down the slope of the alluvial plain. The gathering is seen in the case of the Broad, and the filling up in the Savannah (C. S., 155).

These tidal runways, which open to the sea in a direction away from the main river, are often no doubt former distributaries of the river, at present kept open by the tides. The river delta phenomena merge into the tidal very intimately in this region, and features are due usually to more than one cause. River, tidal, and current action are here blended, with the indications that the tides are the dominant factor in the determination of the shore forms.

The average height of tides at cape Romain is five feet, while the highest observed tides in this area rise from eight to nine feet.

An example of a ratio similar to the South Carolina type occurs on the north coast of Holland (Holl., 2, 3, 4, 5, 6, 9 ; Atlas Univ., 33).

Southern New Jersey Type. — Northward from Winyah bay the ratio is in favor of alongshore action. Areas showing some tidal in and out flow, controlled by alongshore action, are seen on the following sheets (C. S., 152, 149, 148, 123).

When the lagoons are nearly filled, as in southern New Jersey, the longitudinal feature of the shore is not so marked. But in this case, the time element must be considered, a stage later than that in North Carolina probably exists, and the ratio between tide and current is not necessarily changed.

North Carolina Type. — The next ratio taken to illustrate this progressive series is where the youthful shoreline shows continuous offshore bars, broken only at intervals of several miles by tidal inlets. Examples are seen on the following sheets (C. S., 122, 138, 145, 146, 147, 150).

The tides in the region of Hatteras rise from one to three feet, while the rate of the currents is various, being much affected by storms.

Texas Type. — A final example in this series may be taken from the gulf of Mexico, on the opposite side from which the first was taken. On the east side of the gulf the ratio seemed to be in favor of pure tidal action; on the west, however, the alongshore action appears to be practically uninterrupted by the tides, and has determined the form of the Texas bar, continuous for 102 miles (C. S., 210, 211, 212).

"The tide is almost always less than a foot, and its time is very variable and uncertain. Storm tides are the only important ones." (C. S., 211.)

16. Cliffs.

Nip. — A very characteristic feature of the early stages following both uplift and depression has been shown to be the first cut, or nip, made in the initial coast, before the formation of an offshore bar succeeding elevation or foreland succeeding depression, the presence of either of which protects the coast for the time from further attack.

Examples of Nips. — Back of an offshore bar a nip is usually observed, though the scale of many maps is too small to show so faint a cliff.

Nips are also seen in many regions which have been depressed. Drakes estero (Fig. 21).

Brackenridge bluff and Stearns bluff are nips on the initial coast of Grays harbor, Oregon (C. S., 643).

Back of Willapa bar, Washington, the irregular coast was nipped (C. S., 642 and 6185).

There is a nip north of Empire City, Oregon (C. S., 637).

In Chignik bay, Alaska, inside of spit (C. S., 8891).

Behind the marsh in Brown cove, Alaska (C. S., 704).

Both east and west of the delta of the Dwamish river, Washington.

Powder point, Duxbury, Captains hill, and High cliff, Plymouth, Mass., were nipped before the sea built Duxbury and Long beaches (C. S., 338).

Back of the bar in San Rafael bay and behind the dunes in the filled valley of San Francisquito bay, Lower California, nips are seen (H. O., 638).

Todos Santos bay, Lower California (H. O., 1046).

Behind the marsh on Santa Maria island, Chile (H. O., 1209).

In Frische and Kurische bays (Germ., 3, 8, 29, 30, 49, 72, 73).

Irregular Cliffs (Infancy–Youth). — Cliffs occur along ungraded shores, where there is no protection afforded by bars or other forelands. These are characteristically jagged and irregular in youth, becoming more and more gently curved as the graded shoreline of adolescence approaches.

The actual height of these cliffs upon ungraded coasts depends almost entirely upon the character of the country submerged. The 1,000-foot cliff of North cape, Norway, where the waves dance up and down and accomplish but little abrasion, is young; while the low cliffs upon the islands east of Stockholm are also youthful.

Caves are characteristic of this stage of development. Fingals cave is cut by the sea in the sheets of igneous rock in the drowned western coast of Scotland.*

Cliffs cut in the older Paleozoics of the southern uplands of Scotland, 200 to 300 feet high (Scot., 33, 34, 41).

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* Geikie, Scenery of Scotland, 1887, 218, 219.

The western side of Lewis island has a very jagged outline (Scot., 98, 104).

Many fine examples occur on the west coast of Ireland. Particularly fine ones are on Achill head (62), southwest of the Bloody Foreland headland (9), Brandon head (160, 171), and Bray head (182, 190).

George island, Alaska, on the west side of Granite cove (C. S., 741).

Point Colorado to cape Haro, Mexico (H. O., 640).

Sixty per cent of the cliffs on the eastern third of the island of Elba (Elba).

A portion of the Adriatic coast of Austria (Austr., 24, IX; 25, IX).

Curzola island (Austr., 34, XVI).

West coast of Brittany (Fr., 57).

Many good examples in Sweden (Swe., 11, 23, 29, 32, 37, 41, 46, 52; 18, 24, 25, 32, 41, 51, 61).

And there are numerous similar youthful cliffs elsewhere.

Minutely Irregular Shoreline. — The minute irregularity of the shoreline of certain regions is a feature to which field study should be directed. As a working hypothesis may be offered the idea that these irregularities are due to minor differences in resistance in beds at the coast. The irregularity in the cases given below does not appear to be due to alternations in the resistance in successive strata.

(Italy, 177, 178).

(Attica, X).

(Denm., Hilderöd).

(Fr., 28, 29), irregular rocky ledges below high water.

The east coast of Öland island (Swe., 17, 22, 38, 30).

The east coast of Gotland (Swe., 23, 31).

South of Warberg (Swe., 18).

Gently Curved Cliffs (Adolescence). — Drakes Bay (Figure 21), California, shows for about one half of its extent transportation alongshore. Many of the cliffs retain youthful irregularities (C. S., 629).

Captains bay, Unalashka island, Alaska (C. S., 821).

Chirikof island, Alaska (C. S., 796).

Similar conditions prevail on either side of Acapulco harbor, Lower California (H. O., 872).

Transportation is seen practically all along the shore from Chipequa point to Ventosa bay, Mexico (H. O., 876).

The cliffs on seventy-five per cent of the central portion and fifty per cent of the western portion of the island of Elba (Elba).

Many portions of the Baltic coast of Germany (Germ., 84, 85, 12, 23, 24, 39, 58, 59, 60, 115, 42, 64, 28, 26, 27, 92, 93).

At many points along the east shore of the Cattegat (Swe., 4, 8, 13, 18).

Straighter Cliffs (Maturity). — When the initial shoreline following depression is all cut back by the sea, the cliff line of the depressed

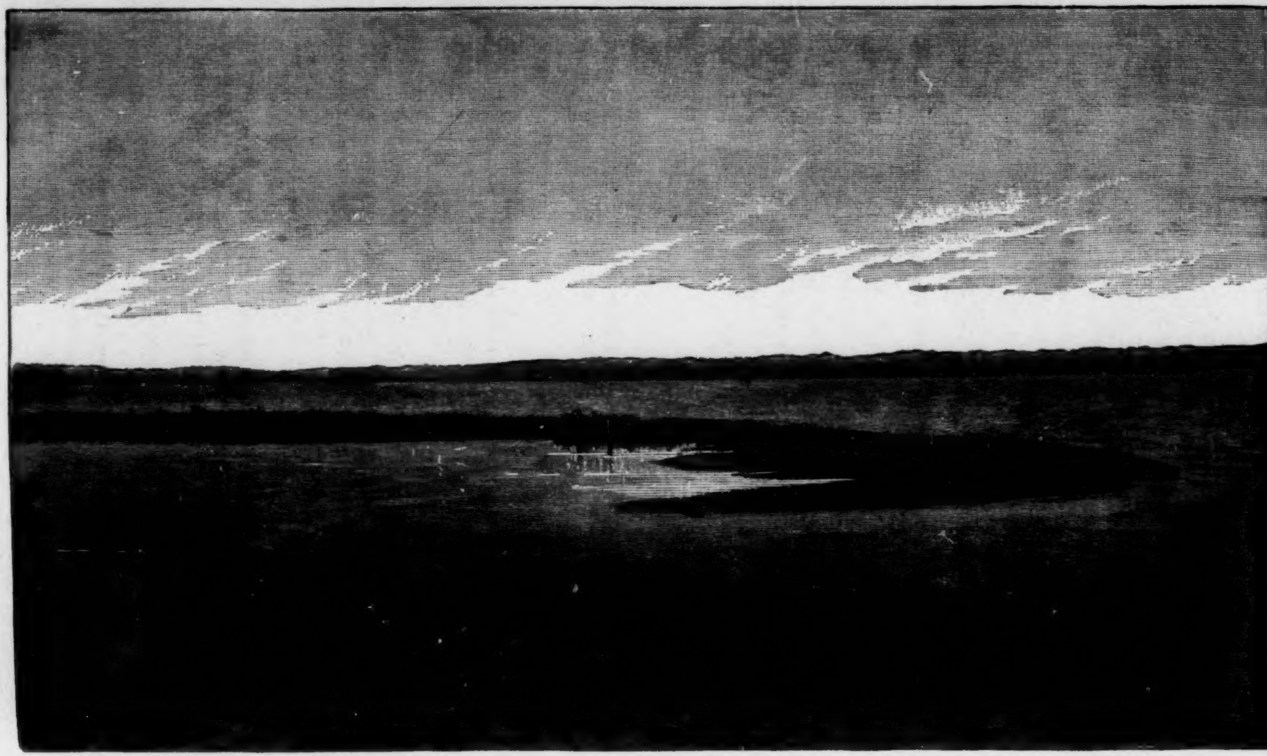

FIGURE 32. Curved Spit: Dutch Point, Lake Michigan. (Plate XXIX., 13th Ann. Rep. U. S. G. S.)

region is nearly straight, as is also the case with the mature cliff upon an elevated region. Distinction between the two must be sought not in the cliff, but in some other sequential feature. In a depressed region the heads of filled bays may still give witness to the drowning. If a coastal plain region was dissected, then depressed, and then its coast was developed to the middle of the stage called maturity, the evidences of the episode of depression would be lost. The northwestern coast of France is probably an example of a region which has gone through some such history. For other examples of straight coasts consult references on pages 243 and 246.

17. Spits.

A Characteristic of Adolescence. — A spit is formed by currents carrying waste from an attached end into open water, where the unattached point of the spit may be shifted by varying conditions of water motion. Spits are found characteristically along adolescent coasts, and may be found wherever there is transportation alongshore, and are particularly marked at the stage of adolescence.

Straight Spits. — Port Angeles, Washington, is enclosed by Ediz hook, which shows an attempt to form a barb (C. S., 6303, old number 646). This may be considered as an earlier stage of the condition seen in New Dungeness harbor to the east.

Putziger spit (Germ., 27, 47).

A spit has grown northeast into the Zuyder Zee from the dike surrounding Urk island (Holl., 20).

Examples of straight spits occur in the Limfjorden (Denm., Lögstör).

The type example of a broad spit is Skagen point, upon the northern extremity of Jutland (Denm., Hirshals, Skagen). The prevailing motion of currents is indicated by offsets and stream deflection to be toward the point of the spit on the right and from the point on the left. In this example we are able to confirm the indications given by the geographic form, as to the direction of the forming currents, by actual observations. The prevailing current along the west coast of Jutland is from the right, the surface water having been shown to flow from the south toward the point of Skagen spit.* The lines of growth are beautifully shown by the curving strips of marshland; even the artificial ditches follow the same curves as if their location was determined by dune ridges. The direction of growth of this spit has been toward the nearest land on the Swedish coast.

Curved Spits. — Dutch point (Fig. 82), lake Michigan, has grown from right to left, looking from the lake to the shore. Storms from the opposite direction have "turned its end toward the land and the successive recurvements are clearly dis-

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* H. Mohn, The North Ocean, Norwegian North Atlantic Expedition, 1876–78, [2,] XVIII. 168, Pl. XLIII.; Danish, Meteorologisk Aarbog, 1880, 1881.

cernible near the apex. The last of these is the greatest; and it is possible that the spit has acquired permanently the form of a hook." *

Hooked Spits. — Cape Lookout † is characterized by a spit projecting from the point of the cusp which has a recurving barbed hook on its left side. The curve of the right side of the spit is continuous with the curve of the right offshore bar, and there is an offset from the right near the point of the cusp proper. On the opposite side of the spit there are three minute offsets, also from the right to the left. The offsets therefore indicate currents flowing in opposite directions upon the two sides of the spit, both moving from the right to the left. The form of the barbed hook is evidence for a current moving from the sea toward the land at this point on the left side of the cusp, because for its extension material must be carried toward the point of the hook from some other locality, and since the hook curves in toward the land and has a smooth contour on the outside and an irregular one on the inside, transportation is inferred along the graded and not the ungraded path. The form of the Lookout recurved spit indicates a current from the land toward the sea on the right and one from the sea toward the land on the left of the cusp.

Capes Obitotchnaïa and Berdianskaïa in the sea of Azov (Atlas Univ., 38) are markedly hooked even on a small scale map.

Messina spit, Sicily, is another hooked spit (Ital. and Sicily, 254).

On the south side of Hjarnö island (Denm., Skanderborg), and southeast of Nyborg (Denm., Nyborg), are two other examples. One forms the harbor of Marstal, aided by artificial breakwaters, another lies five thousand meters to the northwest of the city, and a third hooked spit is about the same distance to the east (Denm , Svendborg).

Another encloses New Dungeness harbor (C. S., 646).

Serpent Spits. — In certain places the currents may be so variable or periodically shifting that the spits do not grow in a straight line or simple curve, but take a serpentine course. In many cases this current irregularity may be due to the form of the bottom, reefs, submerged ridges, etc.

The type example of such spits is that of cape Etolin, Nunivak island, Bering sea (C. S., 896).

Spelmo island has a somewhat similar serpent spit growing northward toward the mainland (Denm., Faaborg).

18. Stages of Development of Various Coasts.

Average Stage. — Taking the criteria as given in this paper as a basis of comparison, the maps of various regions have been studied and compared with any available descriptions; and the regions have then been classified according to the prevailing criteria shown. A few criteria in any region may be in advance or behind the average development of features, and such a region has been classed according to the majority of its features. This classification is not as complete as could be desired,

* G. K. Gilbert, 5th Ann. Rep. U. S. G. S., 96, Pl. IX.

† See page 180.

nor is it free from inaccuracies. The sources of information are in many cases very meagre.

All the reasons for the classification of each example are not discussed; and many of the most important features are omitted, because they already have been considered. Under examples of depression is given some idea of the various kinds of lands which were depressed, and also some hint as to the different stages of development which had been reached before the new cycle was inaugurated.

Uplift: Youth. — The coast of the Argentine Republic (page 162).

Texas (p. 89), and other parts of the Atlantic and Gulf plains.

Maine (C. S. and G. S. sheets), (pages 158, 185, 188).

Corsica (Fr., 261, 263, 265).

Parts of Attica (page 186).

Probably the coast of Brazil from cape Benevento to cape Frio should be here included. The charts show offshore bars enclosing lagoons (H. O., 470, 471), probably following uplift.

Also from cape Santa Marta to Tramandaky bar (H. O., 477).

The southern half of Lower California, Mexico, appears on its western slope to have a coastal plain, described as "low hills and rising plains," with offshore bars enclosing narrow lagoons (H. O., 621).

The western coast of Mexico, east of the gulf of California, also shows a similar coast (H. O., 621 and 622 as far south as San Blas).

A third example in the same general region is seen on the west coast of Guatemala, extending a little on either hand into Mexico and San Salvador (H. O., 931, 932). The detail of bar and lagoon is shown on the chart (H. O., 873). The lack of definite information makes a positive statement in regard to this region unsafe. A study of the maps indicates that they belong in this stage. Mr. J. J. Williams says in regard to this region: "The tertiary clays, gravels, and beds of detritus which cover up so much of the Isthmus along the line of survey, extend on the north side almost to the summit-level, and the base of the hills which lie east and west of it. These deposits being found pretty uniformly spread, even to the depth of thirty feet in some places, as at a point north of the summit-level, and between it and the river Almoloya, are evidences of the slow and tranquil elevation of this portion of the Isthmus above the sea." *

Uplift: Adolescence. — Southern New Jersey (page 184), and other portions of the Atlantic coastal plain.

Uplift: Maturity. — Eastern Italy (page 186). The southeastern and southern coast of the "toe" of Italy (Ital., 246, 247, 255, 263, 264).

The southern coast of Sicily (Ital., and Sicily, 265, 266, 271, 272, 275, 276). The Tertiary strata are considerably deformed and therefore the shoreline is not as straight as in the case of a more simple coastal plain. In a few places along this line the development has hardly reached maturity, as for example west of Pozzallo (276).

Northwestern France (page 241).

* The Isthmus of Tehuantepec, J. G. Barnard, New York, 1852, 149.

The west coast of Holland from the northernmost outlet of the Rhine to Helder at the inlet to the Zuyder Zee (Atlas Univ. 26; Holl., 14, 19, 24, 25, 30, 37). This is a portion of the confluent delta of the Rhine and adjacent streams.

The coast of Belgium (Atlas Univ., 25; Belg., 4, 5, 11, 12, 19).

Depression: Youth. — Southwest Ireland is a typical example of youthful shore evolution upon a vigorous coast (Ireland, 150, 151, 160, 161, 162, 171, 172, 173, 182, 183, 184, 190, 191, 192, 197, 198, 199, 203, 204). A region of strong relief, with transverse trends, dissected to about early maturity, was deeply drowned and exposed to the strong attack of the open sea. Far up into the bays the waves attack the coast and the offshore currents carry away the waste from the jagged cliffs. Grade is reached only in the bay-bars near the heads of the bays.

The southern coast of Curzola island (Austr., 34, XVI).

The west coast of Central America, San Juan del Sur to gulf of Nicoya (H. O., 1016, details in 1025–1034).

Soledad bay and Santo Tomas anchorage, Lower California (H. O., 1044).

Port Islay, Peru (H. O., 1183).

Brayza island, Austria (Austr., 32, XV).

Meleda island, Austria (Austr., 34, XVII).

The southernmost portion of the Austrian coast, in places becoming adolescent (Austr., 36, XIX; 37, XX).

Many portions of the coast of Greece (Attica, III, VIII, XVI, XXI, XXII, and XXIII).

The youthful shoreline of the low coast of Saltholm is markedly contrasted with the adolescent shoreline north and south of Copenhagen (Denm., Kjöbenhavn).

The eastern coast of Schleswig (Germ., 7, 13, 14, 23, 24). The development has advanced to adolescence in many of the more exposed portions of this low coast.

The steep eastern coast of Sweden from Hanö Bay northward to a point on the mainland opposite the north end of Öland island (Swe., 6, 10, 11, 12, 17, 22, 29). It is worth notice how slightly the glacial accidents have here modified the forms due to drowning.

The Stockholm district (page 159).

The irregular cliffs of eastern Scotland indicate youthful shore evolution (Scot., 57, 67, 77, 87).* The development has gone a little farther toward adolescence near Rattray head (Scot., 97), but very jagged cliffs are seen to the west of this head (Scot., 95, 96). The north coast of Scotland (Scot., 113, 114, 115, 116) shows almost no transportation alongshore, although several bays have been partly filled.

The west coast of North and South Uist (Scot., 68, 69, 78, 79, 88, 89) shows a nearer approach to adolescent simplification of outline than their irregular eastern coast.

Taken as a whole the western coast of Scotland, where the sea attack is stronger though the rocks are more resistant, is nearer adolescence than the eastern, where the weaker attack of the North sea has not done so much work upon the less metamorphosed rocks. The time since the beginning of the present cycle may not have been the same in the two areas. As the division lines have been drawn in this scheme, this Atlantic coast of Scotland is about on the border between the two stages. Youthful and adolescent features both occur. Two typical areas, from

* See Geikie, Scenery of Scotland, 2d ed., 1887, 56–59.

the northwest and southwest respectively, are given (Scot., 71, 72, 81, 82, 91, 92, 100, 101; 19, 20, 21, 22, 27, 28, 29, 30, 35, 36, 37, 38, 43, 44, 45, 46).

The shores of Kristiania fjord (Nor., 9, A, B, C, D; 10, A, C; 14, B, D).

The Bergen region with structural northwest to southeast trend (Nor., 16, C, D; 22, A, B; 23, A).

Central Norway (page 159).

Southern coast of Finland (Rus., 11, 25).

The eastern shore of the Cattegat northward from Warberg (Swe., 18, 24, 25, 32, 41, 51, 61).

Coast of Chile (H. O., 445, 446, 446ᵃ, 447, 447ᵃ, 38; also Plano Topografico y Geologico de la Republica de Chile, sheet 12).

The California coast near San Francisco (C. S., 5500, 5520, 5521, 5599).

Depression: Adolescence. — The type example of adolescent shore development following depression is in Germany on a coast of moderate relief upon the southern shore of the Baltic (Germ., 1, 3, 8, 15, 16, 25, 26, 27, 28, 29, 30, 43, 44, 45, 46, 47, 48, 49, 50, 65, 66, 70, 71, 72, 73, 92, 93). Beaches occur at the foot of the cliffs, and the cliff lines are gently curving. The transportation of material takes place practically all alongshore, wings have grown out from the headlands, and the bays are nearly all enclosed by bars. Deltas occur at the bay-heads and are growing forward, but the bays are not as yet filled by land waste and sand blown in from the bars. Upon the inside of the bars there are cuspate projections of sand, while nips are seen upon the mainland itself. At a distance of from 3 to 10 kilometers offshore there is a depth of from 20 to 25 meters, which seems to represent the submarine platform. Offsets, overlaps, and stream deflections are not strong in either direction, but show a slight alongshore action toward the east or left, thus indicating a dominant current from the right. This dominance appears to be stronger toward the eastern side: witness the wing growing eastward from Putzig headland, the inlet to Frische bay nearer the northeast end of the bar, and the inlet to Kurische bay crowded way over to the northeast end close to the mainland.

One feature very typical of adolescence which is not well shown along the northern coast of Germany is island-tying. There are several areas, which were possibly isolated portions of the mainland at the beginning of the cycle, that are now completely connected with the mainland by sea and river aggradation, but there are no typical tombolo-tied islands,* so common elsewhere. The reason for the absence of such islands seems to be that this shoreline is one developed upon a drowned coastal plain, not deeply dissected and somewhat masked by glacial aggradation. The writer's interpretation of the late history of this region is that, after the elevation of the Tertiary and Pleistocene strata of the North German plain, the dissection of the land advanced to adolescence. Then followed a moderate depression by which the adolescent valleys were drowned, but the land was not sufficiently dissected to allow the formation of many islands.

Another example is the west coast of Central America, gulf of Nicoya to Burica point (H. O., 1016, 1017).

Blanca and Falsa bays, Lower California (H. O., 1115).

Playa Maria bay to Rosalia point, Lower California (H. O., 1118).

Bay of Avatcha and approaches, Kamchatka (H. O., 54).

* See page 189.

San Juan Bautista bay, Juan Fernandez island, from Salimas point to Bacalao point (H. O., 1267).

The western coast of Mexico from San Blas to Tehuantepec (H. O., 622, 932, 933; details 876, 915, 936, and 938).

Puget sound (C. S., 6450, 6460).

Transportation occurs along nearly the whole firth of Forth shore (Scot., 32, 33, 40, 41).

The northeast coast of Ireland has entered adolescence (Ireland, 8, 14, 20, 21, 29).

The area of moderate relief in the region of Dublin, from Dundrum bay to Wicklow head (Ireland 60, 61, 70, 71, 81, 82, 92, 102, 112, 121, 130), shows continuous transportation alongshore and other typical features of adolescence.

The eastern coast of Jutland from Skagen to Horsens (Denm., Skagen, Frederickshavn, Aalborg, Mariager, Stavnshoved, Skanderborg). The offsets and river deflections indicate a prevailing current from the left. The shoreline is here much simplified, and for the most part in long swinging curves, but the initial outlines are still seen in the fjorded bays, therefore the shoreline is classed as adolescent approaching maturity.

The east coast of Rügen island (Germ., 42, 64). See also hypsometric map by Dr. R. Credner which shows the simplification of a very irregular shoreline.*

The southeast coast of Möen and Falster (Denm., Moensklint, Vordingborg, Gjedser).† The offsets and stream deflection indicate a prevailing current from the northeast.

Part of the northeast coast of Schleswig-Holstein (Germ., 39, 58, 59, 60).

Southern coast of Sweden (Swe., 1, 2, 3). The streams are deflected to the left, which indicates a dominant current from the right.

The eastern shore of the Cattegat southward from Warberg (Swe., 4, 8, 13, 18).

Portions of the coast of Greece (Attica, VIII, XI, XVII).

The southeast coast of Arabia on the map by S. B. Haines.‡

The coast of Tunis (Tunis, VII, XIV, XXI, etc.).

The northwest shore of the Black sea (Rus., A, 19, 33; Atlas Univ., 38). See page 214.

Depression : Maturity. — The west coast of Italy from Punta Bianca southward to the land-tied island, Massoncello (Ital., 96, 104, 111, 112, 119).

The west coast of the Italian "foot" (Ital., 228, 229, 236).

The western coast of Jutland (Atlas Univ., 30; Denm., Thisted, Lögstör, Lokken, Hirshals, Skagen). A prevailing current from the right is indicated by the offsets.

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* Rügen, Forsch. z. deutsch. Landes- u. Volkskunde, 1893, VII. 373–494.

† See also maps and sketches in Geologie der Insel Möen, by Dr. C. Poggaard, Leipzig, 1852; and for sketches of disturbed strata in cliffs see account by F. Johnstrup, Deutsch. geol. Gesell. Zeit., 1874, XXVI. 533–585.

‡ J. R. G. S., 1845, XV. 104.

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LIST OF ABBREVIATIONS.

Periodicals.

A. A. A. S. = American Association for the Advancement of Science: Salem, Mass.
Am. Geol. = The American Geologist: Minneapolis.
A. J. of S. = The American Journal of Science: New Haven.
Am. Nat. = The American Naturalist: Philadelphia.
Atlan. Mon. = The Atlantic Monthly.
Bull. G. S. A. = Bulletin of the Geological Society of America: Rochester, N. Y.
Bull. Soc. Géog. = Bulletin de la Société de Géographie: Paris.
Bull. U. S. G. S. = Bulletin of the United States Geological Survey: Washington.
C. R. = Comptes Rendus de l'Académie des Sciences: Paris.
C. R. Soc. Géog. = Compte Rendu des Séances de la Société de Géographie: Paris.
Geol. Mag. = London Geological Magazine.
J. A. G. S. = Journal of the American Geographical Society: New York.
Jour. of Geol. = The Journal of Geology: Chicago.
J. R. G. S. = Journal of the Royal Geographical Society: London.
Mem. B. Soc. Nat. Hist. = Memoirs of the Boston Society of Natural History.
Min. Proc. Inst. Civ. Engin. = Minutes of Proceedings of the Institution of Civil Engineers: London.
New Phil. Jour. = New Philosophical Journal: Edinburgh.
Pet. Geog. Mitt. = Petermanns Mitteilungen aus Justus Perthes' géographisches Anstalt: Gotha.
Pet. Geog. Mitt., Erg. = Ditto, Ergänzungs-Heft.
Phil. Trans. = Philosophical Transactions of the Royal Society: London.
Pop. Sci. = Popular Science Monthly: New York.
Proc. Acad. Nat. Sci. Phil. = Proceedings of the Academy of Natural Sciences: Philadelphia.
Proc. B. Soc. Nat. Hist. = Proceedings of the Boston Society of Natural History.
Proc. Geol. Soc. = Proceedings of the Geological Society: London.
P. R. G. S. = Proceedings of the Royal Geographical Society: London.
Q. J. G. S. = Quarterly Journal of the Geological Society: London.
Rep. Brit. A. A. S. = Report of the British Association for the Advancement of Science.
Rev. de Géog. = Revue de Géographie: Paris.
Sci. = Science: New York.
Scot. Geog. Mag. = The Scottish Geographical Magazine: Edinburgh.
Smith. Cont. Kn. = Smithsonian Contributions to Knowledge: Washington.
Trans. Geol. Soc. = Transactions of the Geological Society: London.

U. S. C. G. S. = United States Coast and Geodetic Survey: Washington.
U. S. G. S. = United States Geological Survey: Washington.
Z. d. G. f. E. = Zeitschrift der Gesellschaft für Erdkunde: Berlin.
Z. f. E. = Zeitschrift für Erdkunde: Berlin.

Maps.

Atlas Univ. = Atlas Universel par Vivien de St. Martin: Paris, Hachette & Compagnie. References follow revised numbering of the continuation of the series by Fr. Schrader.
Attica = Karten von Attika, von E. Curtius und J. A. Kaupert, 1 : 25,000: Berlin, 1881–1897.
Austr. = K. u. K. militär-geographisches Institut: Austria, 1 : 75,000.
Belg. = Carte Topographique de la Belgique, 1 : 40,000.
Brit. Ad. = Charts published by Order of the Lords Commissioners of the Admiralty: London, various scales.
C. S. = United States Coast and Geodetic Survey, various scales.
Denm. = Generalstabens Kort over Danmark, 1 : 100,000.
Elba = Carta Geologica dell' Isola d' Elba, 1 : 25,000: Rome, 1884.
Eng. = Ordnance Survey of England, 1 : 63,360.
Fr. = Carte de la France, au Dépôt général de la Guerre, 1 : 80,000.
Geol. Eu. = Carte géologique internationale de l'Europe, 1 : 1,500,000. Beyrich und Hanchecorne, Berlin, 1894.
G. S. = United States Geological Survey, scales, 1 : 62,500, 1 : 125,000.
Germ. = Karte des deutschen Reiches, K. Preuss. Landes-Aufnahme, 1 : 100,000.
Holl. = Topographische en militaire kaarte van het koningrijk Nederlanden, 1 : 50,000.
H. O. = Hydrographic Office, United States Navy, various scales.
Ireland = Ordnance Survey of Ireland, 1 : 63,360.
Ital. = Instituto geografico militare: Italy, 1 : 100,000.
N. J. = Atlas of New Jersey, Geological Survey of New Jersey.
Nor. = Topografisk Kart over Kongeriget Norge, 1 : 100,000.
Rus. = Special Map of European Russia, 1 : 420,000.
Scot. = Ordnance Survey of Scotland, 1 : 63,360.
Sicily = Carta Geologica dell' Isola di Sicilia, 1 : 100,000.
Spain = Memorias de la Comisión del Mapa Geológico de Espana. Mapas, 1 : 400,000.
Spain Bol. = Boletin de la Comisión del Mapa Geológico de Espana. Mapas, 1 : 400,000.
Stieler = Adolf Stieler's Handatlas, Gotha, Justus Perthes, various scales.
Swe. = Generalstabens Karta öfver Sverige, 1 : 100,000.
Swe. Geol. = Sveriges Geologiska Undersökning, 1 : 50,000.
Swiss = Eidgenössisches Militair Archiv, Switzerland.
Tunis = Carte topographique de la Tunisie, Service géographique de l'Armée: France, 1 : 50,000.